THE ROYAL AERONAUTICAL SOCIETY

(Founded 1866*)*

with which is incorporated the Institution of Aeronautical Engineers

VOLUME XXXVIII

The 567th Lecture read before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

SECOND MEETING, FIRST HALF, 69TH SESSION

The Second Meeting of the first half of the 69th Session of the Royal Aeronautical Society was held at the Royal Society of Arts, John Street, Adelphi, London, on Thursday, November 2nd, 1933. In the chair, the President (Mr. C. R. Fairey).

The PRESIDENT: Before proceeding with the usual business he knew he would be reflecting the wishes of the members if he were to place on record an expression of their sympathy with their Past-President, Colonel the Master of Sempill, in the accident that had befallen him. He was, however, very glad to be able to say that the Master of Sempill was doing very well and there was every prospect of his being able to make a complete recovery. There was no need, continued the President, for him to tell the members of the Royal Aeronautical Society of the great work which the Master of Sempill had done not only for the Society but for the whole cause of aviation and he knew that all the members would wish to send an expression of their sympathy not only to the Master of Sempill but also to the Hon. Mrs. Forbes Sempill.

The PRESIDENT, continuing, said that if there is one subject of greater interest than another in aviation it is the question of the variable pitch propeller, an invention which everybody was eagerly awaiting. Nearly every firm or experimental department in the country was experimenting with it and the lecture that evening was to be on this subject by one who was excellently qualified to give it. It was to be hoped that the debate would prove not only interesting but informative, because the lecturer was, in the opinion of the Society, the best man they could find to give such a lecture. After his time spent in war service Mr. Jennings took his Honours Degree in London—the University College engineering diploma—and since 1923 had been engaged in the research and experimental department of the Royal Aircraft Establishment where a great deal of his work had been on the subject he was to talk about. It was therefore with the greatest pleasure that he introduced Mr. W. G. Jennings to the meeting.

VARIABLE PITCH AIRSCREWS AND VARIABLE GEARS

BY

W. G. JENNINGS, B.Sc., A.F.R.Ae.S.

The subject defined by the title of this paper is one which cannot be covered completely in the time at my disposal. I propose therefore to confine my remarks to-night almost entirely to the aerodynamic aspects of the problem and to put before you some possible advantages that may be gained by substituting a variable pitch airscrew for the normal fixed pitch airscrew, and in certain cases to compare the results with those given by the introduction of a variable gear airscrew. The mechanical side of the problem is a subject complete in itself and will not be dealt with here.

The term " variable pitch airscrew " will be used to include any airscrew whose pitch is capable of being altered in the air. There are two main types—the manually operated type, in which the pitch is controlled but not necessarily operated directly by the pilot, and the automatic type, in which the pitch adjusts itself automatically so that some predetermined rate of rotation is maintained under all conditions of flight. In the latter type it is usual to arrange for the governing speed to be under the control of the pilot. In assessing the merits of a variable pitch airscrew it is sometimes necessary to consider the particular method of pitch variation under examination.

Performance in the Air

By performance in the air I mean those two basic items of aircraft performance, namely maximum level speed and maximum rate of climb. At full throttle with a fixed pitch airscrew the power developed during the climb is appreciably lower than that developed at top speed, since the engine rotation rate is less; also at heights greater than the rated height of the engines there is a fall off in engine rotation rate in level flight. By decreasing the airscrew pitch and allowing the r.p.m. to increase, the full power of the engine can be developed; the characteristics and the conditions of operation of the airscrew will of course be altered, and the net effect on the thrust horse-power must be ascertained. In order that some quantitative estimate may be made of the effect of a variable pitch airscrew it is necessary to fix some conditions of operation for which it is assumed that the fixed pitch airscrew is designed. It will be assumed that the fixed pitch airscrew is designed to operate at maximum efficiency at full throttle level speed at the rated height of the engine, and that the engine rotation rate is then a maximum. For many purposes a fixed pitch airscrew may be designed for other conditions, for example in interceptor aircraft where climb may be of primary importance, or long distance travel where range is the chief factor. Other considerations, such as excessive tip speed, ground clearance of the airscrew, etc., may make it impossible in particular cases to satisfy the conditions assumed above. The variations of initial conditions are too numerous to be dealt with in a general survey, and each individual case must be treated on its merits in order to establish precisely the advantage to be gained by pitch variation. It must therefore be borne in mind that the following observations should be regarded as a general indication only of what may be expected from a variable pitch airscrew.

In Fig. 1 the calculated rate of climb of a typical high performance two-seater (4,300lb.) is shown when fitted with a normal engine and with supercharged engines with different rated altitudes. In estimating the performance

the thrust has been debited with the slipstream drag in the usual way. The full lines show the performance with a fixed pitch airscrew. Below the rated height the engine is throttled to keep within the maximum permissible boost pressure, and for the purpose of this calculation it has been assumed that the engine torque remains constant when the boost pressure is constant. The dotted lines show the performance when the pitch of the airscrew is varied to allow maximum permissible r.p.m. under all conditions. It is uncertain if maximum engine r.p.m. would be permitted during a sustained climb, but in an emergency—for example

THE VARIABLE PITCH AIRSCREW
IN CLIMB PERFORMANCE.

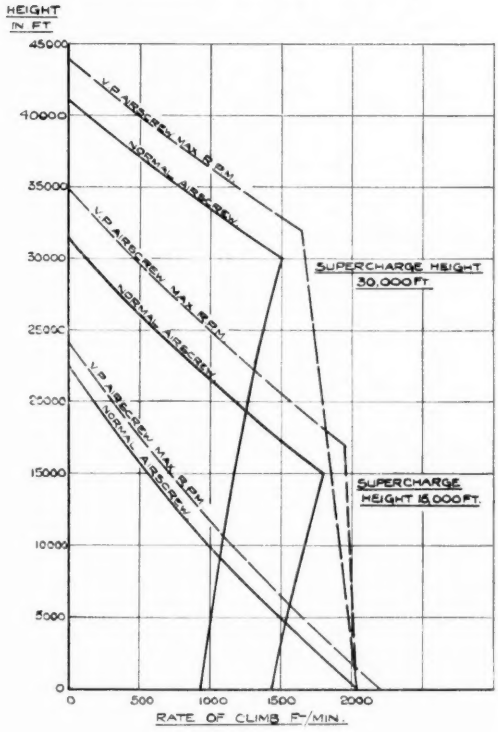


FIG. 1.

in aerial warfare—full use will probably be made of all the available power. It is possible that this method of operation will not always produce the optimum performance with a variable pitch airscrew, since the net result of a change in r.p.m. and a change in airscrew efficiency will depend upon the variation of engine power with r.p.m. and the initial working conditions of the fixed pitch airscrew. An allowance has been made for the increase in weight due to the variable pitch mechanism. It is probable that any successful variable pitch airscrew will be made of metal, and it is obvious that the difference in weight will depend on whether the variable pitch airscrew replaces a wooden

airscrew or a metal airscrew; in this example the additional weight has been taken as 2 per cent. (80lbs.). The increase in rate of climb is small with the normal engine, but an appreciable gain in climb is obtained in the case of the supercharged engines below the rated height. The improvement above the rated height is due mainly to the increase in supercharge height with increase in r.p.m. In the case of a gear driven centrifugal supercharger the improvement in rate of climb due to the variable pitch airscrew is over-estimated, since a large part of the additional power consequent on the higher rotation rate is absorbed in driving the compressor at the increased speed; when this is taken into account the increase is about half that indicated. The increase in climb is due primarily to the increase in engine rotation rate, and corresponding changes in airscrew efficiency are, in this case, of secondary importance. If the engine rotation rate during the climb is limited to normal r.p.m., the advantage of a variable pitch airscrew practically vanishes except in the case of highly supercharged engines below the rated height.

The effect on level speed is small; the fixed pitch and variable pitch airscrews are identical at the rated height, and differ little at other heights. The difference may, however, be more marked if the operating conditions of the airscrew are limited to normal engine r.p.m. during the climb. If the maximum permissible r.p.m. are of the order of 20 per cent. above normal r.p.m. (this is the case with one modern engine), it is improbable that a fixed pitch airscrew absorbing full torque during the climb will be able to reach maximum r.p.m. in level flight, but the variable pitch airscrew will not be so limited.

Static Thrust

An examination of the static thrust of an airscrew will give some indication of the thrust available for take-off. Actually, of course, the thrust of an airscrew varies with the velocity during take-off, and it is necessary to examine the behaviour of the airscrew during the entire take-off to assess the merits of pitch variation. It is convenient, however, to deal in the first place with static conditions and then to consider the effect introduced by the variation of thrust during take-off. The static thrust available for a given engine torque is proportional to the ratio of the thrust coefficient to the torque coefficient of the airscrew (kT_0/kQ_0).* For normal airscrews this ratio increases appreciably as the pitch diameter ratio decreases from 1.5 to 0.5. Before we can find out to what extent the variable pitch airscrew can take advantage of the increased thrust at low pitch settings, it is necessary to make some assumptions with regard to the working conditions of the airscrews. It will be assumed that the variable pitch airscrew rotates at maximum r.p.m. at zero advance, and the fixed pitch airscrew at maximum r.p.m. at top level speed. The powers absorbed by the two airscrews under these conditions will then be the same, and the airscrew torque coefficient will be the same. The appropriate static pitch setting for the variable pitch airscrew to give the same static torque coefficient as the fixed airscrew in level flight can then be determined from the airscrew characteristics.

Fig. 2 shows the variation of kT_0/kQ_0 with pitch setting for a family of airscrews. Assuming that the torque coefficient of the fixed pitch airscrew in level flight corresponds to that at maximum efficiency, in each case a curve representing a family of variable pitch airscrews is obtained by shearing the curve in Fig. 2 by various amounts to satisfy the above conditions. For any given basic pitch diameter ratio the ordinates of the two curves give the relative increase in static thrust that is possible when a fixed pitch airscrew is replaced by a variable pitch airscrew. The increase in static thrust indicated by these curves must be considered as an optimum, and may not be realised in practice. For instance, it may not be permitted to allow the engine to rotate at maximum

* See Appendix.

r.p.m. under static conditions; or the engine torque at full throttle may decrease with increase in engine speed instead of remaining constant as assumed. These limitations would reduce the advantage of pitch variation appreciably. The important conclusion to be drawn from the curves is that no appreciable increase in static thrust is obtainable when the pitch diameter of the basic airscrew is low.

VARIATION OF STATIC THRUST WITH CHANGE OF PITCH.

$T_0/Q_E = (k_{T0}/k_{Q0})\ (1/GD)$.

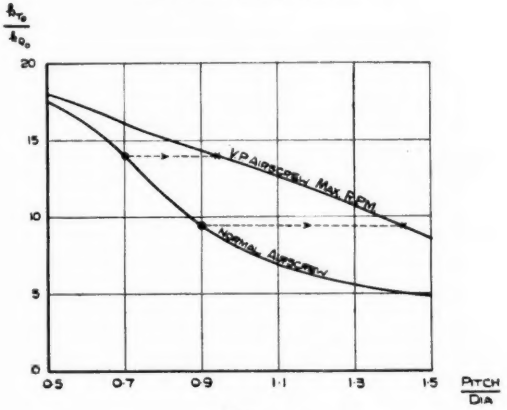


FIG. 2.

With supercharged engines the increase in static thrust due to pitch variation is somewhat more marked. This is due mainly to the necessity of holding down the r.p.m. with the fixed pitch airscrew by throttling, in order not to exceed maximum boost pressure at the ground.

The behaviour of the different airscrews during take-off run will now be briefly examined. The determination of the variation of thrust with velocity in the case of the fixed pitch airscrews presents no difficulties and is immediately calculable from the engine and airscrew characteristics. So far it has been unnecessary to differentiate between the particular types of variable pitch airscrew, but for take-off conditions a knowledge of the method of pitch variation is required. With the automatic airscrew the governor would be set to allow some given rate of rotation—possibly maximum r.p.m.; since the r.p.m. are constant, the torque coefficient is constant, and the appropriate pitch to maintain constant torque coefficient can be obtained by interpolation between a suitable airscrew family. In the case of the manually operated airscrew it would not be permitted to set the airscrew to give maximum r.p.m. at static, since it would then be necessary for the pilot to increase the pitch during take-off to prevent exceeding maximum r.p.m., and this is not practicable; it is probable that, prior to the take-off, the airscrew would be set at a pitch which would allow perhaps maximum r.p.m. at take-off or climbing speed. The airscrew would then behave as a normal fixed pitch airscrew. Curves of thrust against speed, relative to the thrust and speed at maximum top speed (maximum r.p.m. and maximum airscrew efficiency), for the various airscrews are shown in Fig. 3. It is assumed that the automatic airscrew maintains maximum r.p.m., and the manually operated airscrew is set to give maximum r.p.m. at 0.6 times top speed.

The drop in thrust of the fixed pitch airscrew at low speeds is clearly shown, and may be due to partial stalling of the blades. The increase in mean take-off thrust with the variable pitch airscrews is about half the increase under static conditions.

It is a debatable point whether a decrease in the take-off run of modern high-powered land aircraft is really necessary, but the problem of large flying boats is another matter. There it is possible that a variable pitch airscrew may make all the difference between a successful take-off and failure to leave the water.

EFFECT OF PITCH VARIATION
ON " TAKE OFF " THRUST.

T/T_m = thrust/(thrust at top speed).
V/V_m = speed/(top speed).

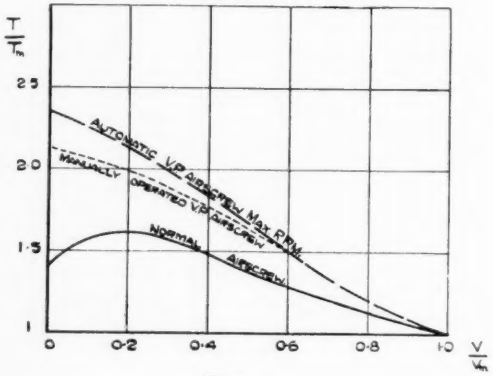


FIG. 3.

Range

I do not propose to deal here with the requirements associated with long range flight by aircraft designed exclusively for this purpose; that is a particular case which demands its own treatment. I shall continue to use as a standard the normal aircraft such as may be used in the Service or for ordinary commercial work where top speed is an important consideration. For a given indicated airspeed the range of an aircraft in miles per gallon of fuel is proportional to airscrew efficiency and inversely proportional to specific fuel consumption.* For level flight the thrust is equal to the drag and for a given indicated speed kT/J^2 is constant. It is obvious that with a fixed pitch airscrew there is only one value of efficiency and specific consumption for a given value of kT/J^2 (at level speed at the same height). With a variable pitch airscrew, however, the efficiency will vary, as the pitch varies for a given value of kT/J^2. The torque required to rotate the airscrew at a given value of kT/J^2 will also vary with pitch setting. Since the specific consumption depends on engine torque it follows that it will also vary as the pitch varies. The problem of the effect on range due to a variable pitch airscrew is then to determine the variation of the ratio of airscrew efficiency to specific consumption with change in pitch setting at constant values of kT/J^2. It is well known that the specific consumption of normal engines increases under throttled conditions. If the pitch of an airscrew driven by a partially throttled engine is increased it will be necessary to increase the engine torque by opening the throttle to fly level at constant indicated speed; hence the

* See Appendix.

specific consumption is reduced. The amount by which the airscrew pitch may be increased is clearly limited by the full throttle torque of the engine; an earlier limit may appear in the form of detonation at large throttle openings and low r.p.m. The variation of efficiency with pitch will depend on the particular value of kT/J^2 under consideration. Examination of the airscrew family shows that over the normal cruising speed range and assuming that top speed occurs at maximum efficiency with the fixed pitch airscrew the efficiency increases slightly

EFFECT OF PITCH VARIATION
ON RANGE.

Range in miles/gall. $= (2810/W)\,(\eta\, L/R)\,(1/C)$.

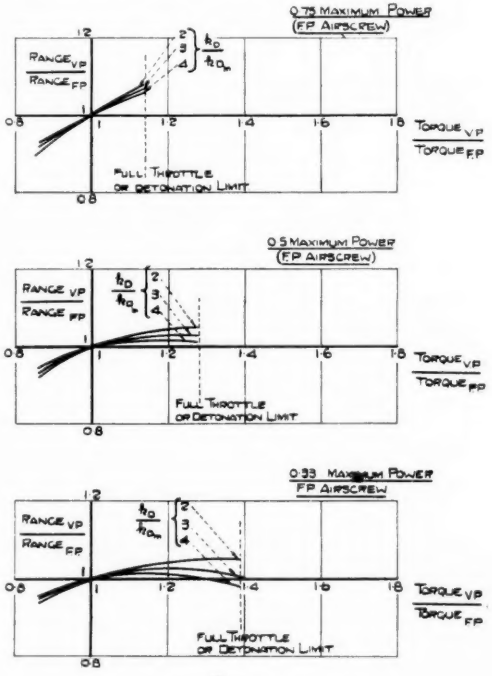


FIG. 4.

as the pitch diameter ratio increases from 0.5 to 0.7 and then decreases for further increases in pitch diameter ratio. That is to say when the basic airscrew has a pitch diameter ratio of 0.7 or more the efficiency will decrease as the torque increases. Fig. 4 shows the range with a variable pitch airscrew relative to the range with a fixed pitch airscrew (pitch diameter ratio 0.7) for various percentages of maximum power available. The ratio of drag coefficient to the drag coefficient at top speed marked on the curves gives some indication of the relative speed of flight. It is seen that at 0.75 maximum power corresponding to a fairly high cruising speed for a normal aircraft the range may be increased by about 8 per cent. The maximum range of a normal aircraft usually occurs between 0.5 and 0.3 maximum power and at a fairly low speed. Under these conditions the increase in range is very small and may be reduced to zero if account is taken of the

additional weight. It appears that the decrease in specific consumption as the torque is increased by opening the throttle is nearly balanced by the decrease in airscrew efficiency at high pitches and low advance per revolution. Actually, of course, for maximum range the speed will vary as the weight is reduced by fuel consumption and a V.P. airscrew can be adapted to suit this change in speed, whereas a fixed pitch airscrew can only be designed to operate at its maximum efficiency at one flight speed. For long range flight, where the change in total weight is large, this will be an added advantage of a V.P. airscrew.

Airscrew as Airbrake

The tendency towards clean aerodynamic design has reduced the minimum gliding angle of modern aircraft, and since the " coming-in " speed is usually in the neighbourhood of the speed of minimum gliding angle the difficulties of landing have been increased. With a variable pitch airscrew the appreciable negative

THE VARIABLE PITCH AIRSCREW
IN HIGH SPEED DIVES.

$$\sin\gamma=(V/V_m)^2\{1-k_TJ^{-2}/(k_TJ^{-2})_m\}(T_m/W).$$

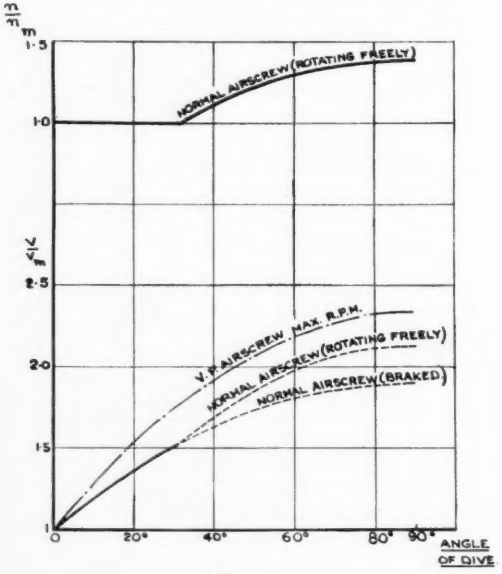


FIG. 5.

thrust associated with zero torque for low pitch aircrews may be used for increasing the gliding angle. For a given aircraft the change in gliding angle, due to the rotating airscrew, is proportional to $kT\,J^{-2}$.* If the engine is throttled right back the power developed will be just about sufficient to overcome the motoring losses and the airscrew will then operate in the neighbourhood of zero torque. An examination of the airscrew family shows that quite low values of airscrew pitch are required to obtain an appreciable increase in gliding angle, but that the

* See Appendix.

angle then increases rapidly as the pitch is reduced still further. Calculations of a typical example give an increase in gliding angle of 3 degrees when the pitch diameter ratio is decreased from 1.0 to 0.3 and a probable further increase of 2 degrees when the pitch diameter is reduced to just under 0.2. This means a large reduction in pitch angle, and since it will be shown later that to take advantage of powered dives a large *increase* in pitch is required, it is desirable that a V.P. airscrew should be capable of a large change of blade angle —in some cases of the order of 30-35°.

High-speed Dives

When diving at speeds in excess of maximum level speed with a fixed pitch airscrew it is necessary to throttle the engine to keep within maximum permissible r.p.m. Ultimately, however, the engine will be throttled right back or

VARIATION OF STATIC THRUST WITH CHANGE OF GEAR RATIO.

$T_0/Q_E = (k_{T0}/k_{Q0})\,(1/GD)$.

($G = 1$ for V.P. and normal airscrew.)

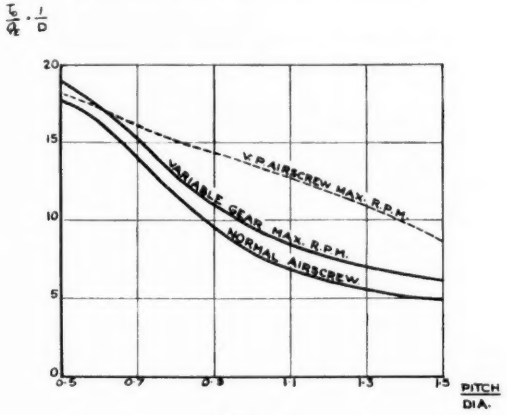


FIG. 6.

switched off, and the r.p.m. can no longer be kept within the maximum permissible but will increase as the speed increases unless the airscrew is braked. If the engine is throttled right back the airscrew, as explained above, will rotate at approximately zero torque; if the engine is switched off the airscrew will act as a windmill to rotate the engine and will operate at a small negative torque. With a variable pitch airscrew it is possible to absorb the full power of the engine without excessive r.p.m. by increasing the pitch. Since, in general, an engine will be adequately cooled at high speeds no difficulty should be experienced in maintaining maximum r.p.m. in a powered dive. An approximate form of the dive equation can be deduced quite simply from the level speed performance and the airscrew characteristics.* The diving performance of an aircraft having a lift/drag ratio at top speed of 5 is shown in Fig. 5, when fitted with a fixed pitch airscrew having a pitch diameter ratio of 0.7 and with a variable pitch airscrew

* See Appendix.

maintaining maximum r.p.m. at all speeds. At 50 per cent. above level speed the fixed pitch airscrew will commence to exceed maximum r.p.m. and at the terminal velocity, *i.e.*, when the angle of dive is 90°, the r.p.m. are about 40 per cent. above maximum permissible. If braked to keep within maximum r.p.m. the terminal velocity with the fixed pitch airscrew is reduced appreciably. With a variable pitch airscrew a higher speed at all angles of dive is obtained.

It is not expected that in diving manœuvres a pilot could manipulate a manually operated variable pitch airscrew to maintain constant r.p.m., and any advantage in aerial fighting can only be considered real if the airscrew is automatic in action.

Variable Gears

It has been suggested that many of the advantages of a variable pitch airscrew could be obtained equally well by a variable gear. I propose to deal quite briefly with the effect of such a gear on certain items of performance to compare with the effect of pitch variation.

EFFECT OF GEAR VARIATION ON RANGE.

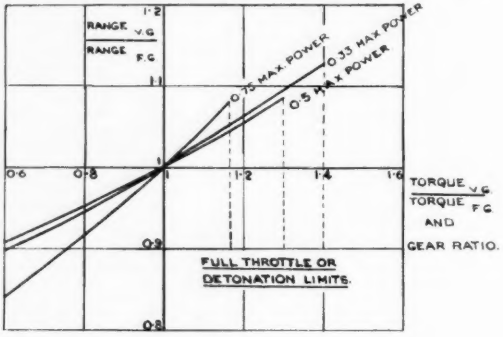


FIG. 7.

With a given fixed pitch airscrew the static thrust can be increased by decreasing the gear ratio between airscrew and engines, thus allowing the engine to develop more power under static conditions. If the engine torque remains constant the thrust is inversely proportional to the gear ratio, and the extent to which the gear ratio may be decreased is governed by the maximum permissible engine speed. For the same airscrew the square of the engine rotation rate is inversely proportional to the cube of the gear ratio for constant engine torque. The value of the static thrust with an alternative gear allowing maximum engine r.p.m. is shown in Fig. 6, and compared with the variable pitch airscrew. It is seen that for large basic pitch diameter ratios, where the increase in static thrust becomes appreciable, variation of gear is less effective than variation of pitch.

The influence of a variable gear on range can be estimated quite easily. It has been shown that for level flight at a given indicated speed kTJ^{-2} is constant, and the range in miles per gallon is proportional to the airscrew efficiency and inversely proportional to the specific consumption. For the same airscrew the efficiency is constant and the range is dependent on specific consumption only. Now the speed and thrust are constant, and therefore the airscrew rotation rate and engine power are constant. Hence the engine torque is inversely proportional to the engine speed and directly proportional to the gear ratio. The increase in range due to a variable gear is shown in

Fig. 7 for various power ratios. As would be expected increased gear ratios are required to give increased range, and it appears that in this case the maximum range may be increased by about 10 per cent. compared with 4 per cent. with the variable pitch airscrew. It should be noted that the requirements of gear variation for increased range are in the opposite sense to those for increased static thrust, and a three-speed gear at least would thus be required to secure both advantages. If the rotation ratio of both airscrew and engine are subject to limitations in high speed dives, then gear variation would offer no advantage, but if only one or the other were so limited, then by suitable gear adjustment the terminal velocity dive could be attained without exceeding the limiting r.p.m., and a large advantage secured over the fixed airscrew, as may be seen by reference to Fig. 5. The improvement would, however, still be less than that obtainable by pitch variation.

Gear variation will have no effect on the gliding angle at normal speeds, since the negative thrust associated with zero torque depends only on the geometry of the airscrew.

Summary

I have outlined very briefly the effect on certain items of aircraft performance of using a variable pitch airscrew in place of the normal fixed pitch airscrew; I have dealt more briefly with gear variation. Even so, I have by no means covered the ground completely, and there remain many circumstances in which the utility, or otherwise, of a variable pitch or variable gear airscrew may be demonstrated. In my opinion there are very definite advantages to be gained by a successful method of pitch variation in the air, and to lesser extent by gear variation, but before the merit of either of these devices can be assessed careful attention must be given to the conditions under which it is proposed to use them.

Finally, I must add that I am indebted to the Air Ministry for permission to read this paper, but the views expressed therein are entirely my own.

APPENDIX

Static Thrust

Let T_o = static thrust = $kT_o\rho n^2D^4$
G = gear ratio, airscrew : engine
Q_o = airscrew torque = $kQ_o\rho n^2D^5$
Q_E = engine torque = GQ_o
$\therefore T_o/Q_E = kT_o/kQ_o \cdot 1/GD.$

With a variable pitch airscrew G and D are constant, and T_o is then proportional to kT_o/kQ_o for a given engine torque. With a variable gear kT_o, kQ_o, and D are constant, and T_o is inversely proportional to G for a given engine torque.

Range

Let L = lift
c = specific consumption in lb./b.h.p./hr.
V = forward speed in miles per hour
P = engine horse-power
R = total resistance
η = airscrew efficiency.

For level flight the drag is equal to the thrust

$$\therefore 88/60 \times RV = 550\eta P.$$

Now range in miles per lb.

$$= V/cP = 550 \times 60/88 \times \eta/Rc$$

$$\therefore \text{range in miles per gallon} = 2810\ \eta/Rc.$$

For constant speed R is constant, and the range in miles per gallon is then proportional to η/c.

Airscrew as Airbrake

Let R = total drag
W = weight
T_z = thrust at zero torque
S = wing area
V = speed in glide
V_s = stalling speed
γ = angle of glide.

With no airscrew or at zero thrust the gliding angle, to the first order, is given by $\gamma = R/W$. Assuming the airscrew to operate at zero torque during the glide the expression for the gliding angle becomes $\gamma = (R - T_z)/W$. Hence the increase in gliding angle due to the airscrew is given by $\Delta\gamma = -T_z/W$.

Now

$$T_z = (kT J^{-2}) \times \rho V^2 D^2.$$

Hence

$$\Delta\gamma = -(kT J^{-2})_z D^2/S (V/V_s)^2 \, 1/kL \text{ max.}$$

Thus $\Delta\gamma$ is proportional to $(kT J^{-2})_z$ for a given gliding speed.

High-speed Dives

Let T = airscrew thrust
R = total drag
W = weight
γ = angle of dive.

The dive equation is given by $T = D\text{-}W \sin\gamma$.

Assuming that at speeds greater than maximum level speed the drag is proportional to the square of the speed and denoting top level speed conditions by the suffix m, we have

$$T = T_m (V/V_m)^2 - W \sin\gamma \text{ since } T_m = R_m.$$

Hence

$$\sin\gamma = (V/V_m)^2 \{ 1 - kT J^{-2}/(kT J^{-2})_m \} T_m/W.$$

For a given aircraft W/T_m is of course constant and is equal to the lift/drag ratio at top speed. Its value is given by the product of the " effective " power loading and the maximum level speed, *i.e.*, $W/(\eta P)_m V_m$, and for most aircraft would be between 3 and 7.

Discussion

The President: He had been impressed, as no doubt all those present had been, by the open-minded way in which the subject had been approached in the paper, which indicated the author had studied it very deeply and was not a man who was mesmerised by the possibilities. Theoretically to examine these possibilities before wrestling with the mechanical difficulties was obviously putting the cart before the horse, but it was the correct way to approach the problem and one most likely to lead to results. The paper had shown very clearly that although there were considerable possibilities along certain lines, the wilder claims made on behalf of variable pitch airscrews were not justified, at any rate as far as their application to aeroplanes was concerned. Possibly the airship enthusiasts would have views rather different from that however.

There was one point mentioned in the paper which had impressed him and upon which he would ask the author a question. The first curve showed the effect of the application of the variable pitch propeller to climbing. The author

had also stated that the effect on speed was small and it was obvious that the principal result obtained was in take-off and then only in heavily loaded machines. The curve showed that although the effect of the variable pitch airscrew was rather small the effect of increasing the supercharger on the engine was very great indeed. The author had estimated the additional weight of the variable pitch propeller at 80lbs., but in that connection he would like to ask a question, although it was perhaps one that might be asked of some of the designers present. What would happen if the extra 80lbs. weight was put into the engine instead of into the propeller in view of the big advantages obviously to be obtained by supercharging compared with the small advantage to be obtained from altering the pitch? This brought him to one other point in connection with the curves showing the amount of variable pitch. He knew the angle changes concerned were small, but would the results be affected in any way if they were calculated on the variable angle rather than on the variable pitch?

Mr. HOLLIS WILLIAMS, A.F.R.Ae.S.: There were two important aspects of the variable pitch airscrew, viz., the aerodynamic problem and the mechanical problem. The author had given a most interesting survey of the aerodynamic problem, and as the President had pointed out it was no use rushing into variable pitch airscrew development without understanding exactly what was going to be obtained from it. There were many cases in which the variable pitch airscrew represented a mechanical complication which was not worth while, and the author had set that out very clearly in the paper. From that point of view the paper could be accepted as a standard work on the advantages and disadvantages of the variable pitch airscrew. Personally, he was sorry the author had not gone into the mechanical side of the problem, although perhaps that was a wise course to adopt as innumerable solutions had been proposed, although few had been given a practical trial. He had not had an opportunity of studying the paper prior to the lecture and would therefore try to contribute one or two ideas on the subject which might be of interest instead of dealing primarily with the paper. For instance, in certain circumstances of low speed range aircraft it was probably best to employ added weight by boosting up the engine rather than embarking on the mechanical complication of the variable pitch airscrew, but there were instances even in the case of low speed range aircraft which the author had not mentioned in which the variable pitch airscrew could be of advantage. One was the twin-engined aeroplane in which failure of one engine led to poor operating conditions for the remaining airscrew, and in this case the variable pitch airscrew would help to bring the machine home even with a heavy load. Nevertheless, in spite of these advantages, in the speaker's opinion we had been wise to keep off the variable pitch airscrew as long as possible. At the same time we could not shut our eyes to the aerodynamic developments that were going on in the direction of high lift devices leading to high loadings and high speed ranges.

In general, however, the advantage of high lift devices was felt in approach and landing and the take-off was apt to be poor, especially with a badly stalled fixed pitch airscrew.

The speaker thought, therefore, that the time had come when through aerodynamic development we had no option but to accept the variable pitch airscrew in spite of its mechanical complications.

The lecturer had mentioned the advantages to be derived from the use of variable pitch, by using maximum permissible r.p.m. at speeds other than maximum level speed.

The speaker felt that this would have to be taken up seriously as the present limitations on engine speed offered no encouragement to the commercial development of variable pitch airscrews.

He was not asking for engines to be run continuously at maximum speed, but that the association of maximum engine speed only with the maximum forward speed of the aircraft should be revised, and that the present period of five minutes

at maximum engine speed should be permitted for take-off and initial climb also. The matter was bound to be brought to a head in the near future, due to the development of various types of experimental high speed range aircraft, which although highly efficient when in the air would be likely to suffer for a dangerously long take-off with a fixed pitch airscrew. An interesting situation would develop under the present engine rules if one such aircraft should be fitted with a variable pitch airscrew which cured the take-off trouble by running for a short period at maximum engine speed. One can imagine the discussion which would take place between the manufacturer concerned, the governing authority and other interests.

The general conclusion was, however, that the difficulties connected with the variable pitch problem must be faced and a practical solution found in the near future.

Senor DE CIERVA, A.F.R.Ae.S.: His contribution to the discussion would consist in emphasising the importance of the variable pitch airscrew where the speed range was large. In the case of the autogiro, too, the variable pitch airscrew was of advantage to a greater extent, perhaps, than in the case of ordinary aircraft, because it permitted of a large increase in static thrust which would enable the autogiro to take-off in small places surrounded by obstacles as well as to appreciably diminish the minimum horizontal speed. Therefore an increase of static thrust was of the greatest importance to the autogiro. If a variable pitch airscrew could be made light, reliable and cheaply, it would be a very great contribution to the progress of aviation.

Dr. WATTS, F.R.Ae.S.: He emphasised what the President had said, viz., that the paper did not strike one as being by an enthusiastic optimist for the variable pitch propeller nor by a hostile critic. It was, indeed, a very impartial scientific summary of the subject to which anybody could turn and get a very fair idea of what the variable pitch propeller could do. Opinions had been expressed —and he had expressed them himself at times—that the advantages of the variable pitch propeller were so limited in magnitude that possibly the weight and expense and increased mechanical complication made the price to be paid too great. Whenever he had expressed such an opinion discussion had always followed in which the participants had been very vague as to what *were* the aerodynamic advantages of the variable pitch propeller. Therefore, the author had been extremely wise in limiting himself to the one aspect, viz., the aerodynamic advantages of this type of propeller and it was to be hoped that in any discussion on the paper the speakers would limit themselves in the same way because the discussion could get very involved if the mechanical difficulties were dealt with. They were subject matter for another paper.

Undoubtedly the paper had been a difficult one to prepare and it was also a difficult one to discuss because, although many people would like one to express a definite opinion as to whether the variable pitch propeller was worth while or not, it was quite impossible to do so because, in the closing words of the paper: "Before the merit of either of these devices can be assessed careful attention must be given to the conditions under which it is proposed to use them."

The paper clearly showed one thing, however, and that was that one should keep an open mind and be ready to use the variable pitch propeller when the conditions were such as to make its use worth while. An illustration was given in the paper where it was shown that for a pitch diameter ratio of 0.7, the advantages were very small and therefore the designer some 10 or 15 years ago who dismissed the variable pitch propeller as not worth while was probably quite correct. At the present time, however, owing to the greatly increased use of gears and the increase in the maximum speed of aeroplanes, propellers with pitch diameter ratios well above the figure mentioned were in general use, up to 1 to 1.5 and with the supercharged engine well to the fore the designer even now might be right in considering the variable pitch propeller not worth while, but it

was nevertheless necessary to consider the whole question very much more cautiously before a definite decision could be arrived at. The one thing which could be said quite frankly about the paper was that no one could seriously quarrel with the general conclusion of the author. Perhaps the worst criticism that could be made—and he believed the author would admit it—was that he had shown the very best case for the variable pitch propeller. The actual advantage obtained would in concrete cases be less rather than more. For instance, the case of climb in Fig. 1 is based on the assumption that the variable pitch propeller can run at maximum permissible r.p.m. the whole time. As we were governed at present, the speed would be limited to normal r.p.m., and except for highly supercharged engines, the advantage largely disappears. It followed that the value of the variable pitch propeller depended to some extent on the rules governing the use of engines and their rate of rotation in various countries. Thus, the variable pitch propeller might be more useful in America than here because our rules concerning how we should use our engines were different. In saying that, however, he was making no criticism of the rules which govern the use of normal maximum permissible r.p.m. If by adaptation of the permissible r.p.m. to different conditions of flight and by ground boosting it was possible to overcome the natural defects of the fixed pitch propeller, that was possibly a better, cheaper and safer way than by using the variable pitch propeller. He did not altogether agree with Mr. Hollis Williams' criticism of the limitation on maximum permissible r.p.m. As he viewed it, the engine had been type tested and approved for continuous running at a certain speed called normal r.p.m. and he looked upon the permission to run it a limited period in excess of this speed as a concession to be thankfully received rather than fought. The fixed pitch airscrew could not usefully take advantage of more than a 15 per cent. excess of maximum r.p.m. over normal r.p.m. and the permissible excess therefore tended to be limited to that amount. The variable pitch airscrew could take advantage of a greater excess and it would therefore become a matter for discussion with the engine makers as to what excess could be allowed with such an airscrew. The author had omitted one advantage of the variable pitch propeller. That was the case of multi-engine aircraft. In that case not only would variable pitch reduce the drag on the idle propeller, but it would also restore the revolutions to the other engines.

In general, concluded Dr. Watts, he was in agreement with the author's summing up. There were advantages to be gained in many cases by the use of the variable pitch propeller, but there remained a further question which could only be discussed in another paper and probably could only be answered by actual experience over a considerable time, viz., whether the price to be paid for the advantages, which were admitted, was not too high.

Air Commodore CAVE-BROWNE-CAVE (Director of Technical Development): He had listened to the paper with great interest. It seemed to him that the test conditions required for engines used with the variable pitch propellers might well have to be different from those for engines used with fixed pitch propellers. The considerable gains in performance which the lecturer had claimed for the variable pitch propellers seemed to come very largely from using the engines under conditions for which at present they were not designed or tested. Maximum permissible r.p.m. were used for longer periods than those at present allowed, and the use of steep pitches at low revolutions, to obtain cruising economy, might lead to difficulties with the present engines. He thought these practices need not be feared if the engine were designed and tested for the conditions of use which were necessary to take advantage of the variable pitch propeller.

Dr. LACHMANN, F.R.Ae.S.: He agreed with what Mr. Hollis Williams had said with regard to the use of variable pitch airscrews on aircraft with very high speed range. Fig. 3 in the paper clearly showed the resulting advantage. There was, however, one other point which referred more to the actual problem of

obtaining variable pitch. The main disadvantage of the variable pitch airscrew in its present form was the high weight and price due to the mechanical method employed to obtain the change in effective blade angle. It seemed to him rather strange that nobody as yet had ever tried to change this effective blade angle in a different way, *i.e.*, in a purely aerodynamic way. Means were known in connection with aerofoils by which it was possible to shift, so to speak, the lift curve of an aerofoil parallel to itself along the angle of incidence line without altering the geometric angle of incidence, *i.e.*, without rotating the blade. It seemed to him worth while investigating whether it would not be possible to design a variable pitch airscrew without rotating the blade, *i.e.*, on purely aerodynamic lines. In congratulating the author of this paper, he said he had been particularly impressed by the simple and clear way in which the physical facts had been represented without the usual display of mathematics common with papers dealing with this subject.

Mr. H. A. METTAM, F.R.Ae.S.: It was significant of the lack of practical progress that the author had to base his tests on the family of fixed pitch airscrews and was not yet able to make any deductions from trials of actual variable pitch airscrews. Work on these lines was done by Dr. Bairstow and his staff at the Air Ministry 15 years ago and it would be interesting to see whether, when variable pitch airscrews came into actual use, all the theoretical predictions of their performance would prove to be right. The author had stated that the speed increase was almost negligible and he would like to inquire if that was really the fact when very near the ceiling with supercharged engines. The author had also mentioned an increase of 20 per cent. from the normal permissible r.p.m. to maximum r.p.m. in a particular engine. It was not difficult to guess which engine was referred to and, as a matter of fact, the normal r.p.m. of that engine had been increased so that the further increase to maximum was now 15 per cent. He believed the author would agree that it is now possible to design a fixed pitch airscrew which would give normal r.p.m. when climbing and would actually attain the permissible maximum at top speed, *i.e.*, the engine makers had altered their rules to suit the operation of the fixed pitch airscrew.

In Fig. 3 of the paper the author had omitted the zero line and thereby given an appearance of greater improvement in static thrust unless one was very careful in judging the curve. This curve appeared to be based on a pitch diameter ratio of about 1. He would like to inquire, however, whether a still greater improvement could not be achieved with a pitch diameter ratio of 1.5. He had intended to raise the question of the use of the variable pitch propeller on multi-engine aircraft, but that point had already been dealt with by previous speakers. There was, however, still the question of the possible use of variable pitch propellers on tandem engine machines. In case of the front airscrew ceasing to work it seemed to him that the advantages of the variable pitch propeller for the rear engine would be very marked and he would like the author's opinion on that matter. In conclusion, Mr. Mettam said that for many years he had believed in the great possibilities of the variable pitch airscrew and he hoped that some day the theoretical predictions of the performance of such airscrews would be realised in practice.

The 15 years' old investigations mentioned were not so comprehensive as those described by Mr. Jennings and were, of course, based upon an earlier series of airscrew tests than those used by him. The results of the old work were applied to estimation of the improvement in take-off by Mr. McKinnon Wood in R. & M. 680. To Mr. Jennings, however, belongs the credit of pointing out the very great importance of pitch diameter ratio. Any full-scale experiments in varying pitch which have been carried with small pitch diameter ratios will have to be regarded as tests of the mechanism, and any disappointment arising as the result of such tests can be discounted. By his theoretical investigations, there-

fore, Mr. Jennings has shown the way to a considerable saving of fruitless practical experiments.

Mr. C. H. GRIFFITHS, A.F.R.Ae.S.: He emphasised the point that quite a large proportion of the gain shown in the diagrams for the variable pitch airscrew had been obtained by taking more power from the engines. In other words, the gain was being obtained at the possible expense of engine reliability. As regards weight, he did not think it fair to take the 80lbs. increase in the airscrew as representing the total increase if the engine is to be run at higher speeds. It is possible, and likely in some cases, that in order to maintain the standard of reliability in the engine, extra weight would be required in the engine and the additional weight of engine and airscrew would, in turn, involve a further increase in weight of the aircraft structure.

As to the vexed question of allowable speeds—particularly with regard to Mr. Hollis Williams' remarks—the present basis of rating British aero engines is to rate them at a certain normal crankshaft speed which is approved for continuous running, such as in a long climb. The airscrew designer is allowed to design his airscrew for full throttle level flight at a crankshaft speed 15 or 20 per cent. above the approved normal speed which is determined by actual type test of the engine. In many cases a fixed pitch airscrew designed on this basis allows crankshaft speeds approximating to " normal " in the climb, *i.e.*, the highest speed established for continuous running. In America he understands the procedure is to have the same so-called normal or rated r.p.m., but the designer is forced to design his airscrew for a crankshaft speed not higher than 5 per cent. above the normal in level flight. A fixed pitch airscrew designed on this basis holds the engine well below " normal " in climb and there is more chance of a gain by fitting a variable pitch airscrew.

Generally, if by using a variable pitch airscrew, variable gears, high boost, or by any other means it is possible to get more power out of the engine, some gain in aircraft performance is to be expected.

Captain BARNWELL, F.R.Ae.S.: In certain cases the addition of variable pitch gear would be of great value; in certain other cases it would be of practically no value; in many cases it would, as was usual in engineering, be difficult to decide whether its employment were justified. If maximum *permissible* r.p.m. were 15 per cent. higher than maximum *normal* r.p.m., and maximum *permissible* b.h.p. then approximately 15 per cent. greater than the maximum *normal* b.h.p.; if, further, the airscrew were designed (according to " standard " British practice) to absorb maximum *permissible* b.h.p. at maximum *permissible* r.p.m. at the level speed which the aircraft would thereby attain, then r.p.m. and b.h.p. would both be approximately maximum *normal* at optimum climbing speed. Hence, in this particular case, no increase of performance could be obtained " legally " by variable pitch or variable gear. The engine, however, must be throttled to maximum *normal* r.p.m. for continuous level flight and then the speed would be about 85 per cent. of the top speed, whilst the power expended would be about 70 per cent. of the maximum *normal*. With a variable pitch airscrew this " cruising " speed could be increased by increasing the pitch and thereby calling for *more power from the engine at normal maximum r.p.m.*

It should be emphasised, continued Captain Barnwell, that variable pitch cannot affect appreciably airscrew efficiency. Improvements in performance due to its use were because the engine was allowed by it to give higher powers than it could with a fixed airscrew. For take-off the variable pitch airscrew would give definite improvement for any machine and in many cases this gain might be of extreme value.

As regards the 2 per cent. addition of weight which the author assumed for variable pitch gear; assuming this as reasonable, it would entail another $\frac{1}{2}$ per cent. increase of structure weight for retaining strength, or an actual increase of $2\frac{1}{2}$ per cent. This would mean $1\frac{1}{4}$ per cent. increase of landing speed.

Looking at this matter fairly and impartially, they needed the variable pitch airscrew because it would be of very great advantage in particular cases, but they must not look upon it as an universal panacea.

In conclusion, Captain Barnwell said he would like to ask two questions, probably foolish ones. The author had stated that his curves for climb were not those for a gear-driven supercharger. Had he then based his calculations on a turbo-exhaust driven unit? If so, why; as he was under the impression that nearly all modern superchargers were gear-driven? Again, the author had mentioned that when throttled, the power developed by the engine was equal to its friction and pumping losses; in other words, that it could be assumed that when an engine was fully throttled the airscrew was windmilling freely. Would the author say what authority he had for this, because the drag of a propeller windmilling varied very greatly with the degree of braking then applied to it?

Mr. R. S. Capon, F.R.Ae.S.: He expressed the view that the paper was rather a review of the position with regard to the variable pitch airscrew and variable gears than providing any advance of our knowledge of this subject. The paper had summarised in a very clear way the available evidence, and that such a summary was necessary could be illustrated by the fact that so far as he was aware there had not yet been a test of the effects of varying the pitch, in this or any other country, where any marked improvement of performance had been obtained or would have been expected; in every instance the pitch ratio had been so low that no appreciable improvement could be anticipated. The chief feature of the problem was the dependence of the advantages of the variable pitch airscrew on the pitch diameter ratio and the question, therefore, of whether we are likely to require variable pitch airscrews in the future depended primarily on whether we are likely to have airscrews of sufficiently high pitch diameter ratio. An important application of the variable pitch airscrew was to improve the take-off of flying boats, but there were not in fact at present many flying boats in which any marked increase of take-off thrust could be obtained because the pitch diameter ratio was too low. The use of gears had a tendency to put up the pitch diameter ratio, but engine designers had to some extent used gears to enable them to obtain higher engine r.p.m., an entirely justifiable thing to do because it gave a very valuable increase in engine power. He did not know whether further gear reductions which would permit lower airscrew r.p.m. and therefore higher pitch diameter ratios were possible in the future. Increase of speed of flight would also lead to an increase in the pitch diameter ratio and the advantages of the variable pitch airscrew would then become greater.

Mr. E. C. Gordon England, F.R.Ae.S. (*communicated*): The point may be considered academical, but in spite of this, might he suggest to Mr. Jennings and others discussing variable pitch propellers, that they use more exact terms. A variable pitch propeller does not indicate necessarily one where the blade angle is changed either by some system of control at the will of the pilot or automatically. In future could they agree that variable pitch propellers are those in which the blade can be set to any predetermined angle while at rest, propellers whose pitch angle is under control during flight at the will of the pilot should be termed controllable pitch propellers, and those automatically controlled, automatic variable pitch propellers?

Mr. Jennings, in his paper, indicates that he foresees some difficulty in the pilot controlling the pitch of the propeller during the take-off; but must this be so necessarily? Would not the electrically operated controllable pitch propeller, designed by W. R. Turnbull, F.R.Ae.S., and manufactured and sold by the Curtiss-Wright Corporation in America (Mr. W. R. Turnbull is incidentally a very old member of this Society) be entirely satisfactory, as the necessary pitch increase can be made without the pilot taking his hands off his controls for one instant.

It would have been interesting if Mr. Jennings could have developed the subject of the effect of reversing the pitch of the propeller at speeds below the

actual landing speed of an aircraft, as in my view its potentiality as an air brake is probably the most important practical consideration of all the advantages claimed for the controllable pitch propeller.

He noticed that Mr. Jennings does not refer to the weight factor of variable gears. Surely this should be taken into consideration in precisely the same way as the weight of the variable or controllable pitch propeller is accounted for.

He would like to say that Mr. Jennings' contribution, valuable as it is, seems incomplete, and that following on his very fair examination of the aerodynamic aspects of the problem, a paper was needed on the practical developments to date and the mechanical problems experienced.

In conclusion, it appears in listening to the many speakers on this subject there is a tendency to consider the problem in terms of military requirements; the commercial aspect seems almost ignored. From purely theoretical and technical aspects in their military sense it may be argued that the advantages of the controllable pitch propeller are small. The significant fact must be faced that in America a great deal of development work has been done, and controllable pitch propellers are now in fairly general use on commercial air liners, and it will be deplorable if we in this country lag behind development in other countries through a distorted view of the requirements of the situation, due to assessing everything in terms of military needs. He was reminded of the able technicians and engineers in this country who for years in the motor industry were contemptuous of the virtues of the electrical self-starter and proved conclusively (to their satisfaction) that there was little or nothing in it; and it was not until America forced the self-starter upon them through the weight of public demand that they finally succumbed to the needs of the situation.

Must history repeat itself to-day?

Mr. C. C. WALKER, F.R.Ae.S. (*communicated*): The V.P. propeller may be a luxury on slow civil, or even on fast military aircraft, but there are no two ways about it so far as fast machines carrying large loads are concerned. The V.P. propeller then becomes a necessity for getting out of aerodromes, and even a superabundance of horse-power would not provide much of a remedy for a stalled propeller.

To look at this matter in a somewhat crude and practical way, one may say that propellers designed for maximum efficiency up to about 130 m.p.h. do not suffer unduly in take-off.

In other words, the weight per b.h.p. installed may still be used as one of the factors governing the take-off characteristics.

In the case of a propeller designed for maximum efficiency at, say, 180 m.p.h. the case is very different, and if a forward speed of 20 m.p.h. is considered as being representative of the early part of the process of getting under way, the 180 m.p.h. propeller will produce only about half the relative thrust horse-power of that designed for 130 m.p.h.

This really amounts to saying that the high speed commercial aircraft is not a practical proposition without the V.P. propeller, and this would appear to be in agreement with what has been found in the United States in actual practice.

The rough figures given above had been deduced from recent data (N.A.C.A. 378) and would no doubt agree with those given by Mr. Jennings. One might sum the matter up from the air transport point of view thus:—

A propeller must be fitted which will give its maximum efficiency at the top speed of the aircraft. This propeller will be suitable for cruising. If the speed of the aircraft is high this propeller will be prohibitively wasteful for take-off (including climbing at low speed) and a V.P. propeller will be necessary to deal with take-off, but is not wanted for anything else.

Attempts have been made to make use of the forces on the propeller to produce a certain amount of self-flexing of the desired kind, but so far with only

just perceptible success. This would provide an attractive solution were it possible to get more of it.

The two-speed gear, as Mr. Jennings shows, is hardly worth the trouble.

Air Commodore J. A. CHAMIER, A.F.R.Ae.S. (*communicated*): Reading the discussion, he did not see any record of the views of anyone who had flown such a device. Might he say that as one who has flown two of the most developed variable pitch airscrews in the U.S.A. that the improvement in take-off and in angle and rate of climb was most marked. This is due, as several members suggested, to permission to use the maximum r.p.m. for take-off and climb for short periods, and he was glad to see that the D.T.D. did not foresee any great difficulty in obtaining such permission.

In level flight in the case of a variable pitch airscrew with an unlimited choice of pitch between maximum and minimum, it was a fascinating experience to see the air speed increase at the same time as revolutions decreased when changing up from the low pitch position with intelligent use of the throttle.

The variable pitch propeller will show to additional advantage with the use of flap equipped aeroplanes and, in conjunction with a flow meter, should offer opportunities for economical cruising. He did not think that many people realised the gain in performance in practical use.

REPLY TO DISCUSSION

As the President had remarked, the extra 8olb. weight might be put into the engine instead of into the airscrew, but he was not able, until he had thought more about it, to give any definite figure for the consequent improvement in performance. At the same time he suggested that improvement in rate of climb or top speed, due to pitch variation, was of minor importance compared with other advantages such as increased static thrust, etc.; here the corresponding increase in engine power could not equal the improvement due to a variable pitch airscrew. With regard to the President's second point, calculations based on constant pitch airscrews or constant blade shapes at different angle gave sensibly the same results.

One or two further examples had been given by Mr. Hollis Williams in which the variable pitch airscrew might be used with advantage, as in the case of the twin engine or multi-engine aircraft when one engine failed. He himself had appreciated that and there were other cases which time had not permitted him to mention. For instance, there was the case of flying boats which sometimes got into difficulties when taxying and he believed their manœuvrability on the water might be greatly improved if they were provided with airscrew pitch variation. The question of maximum r.p.m. versus normal r.p.m. had been mentioned by Mr. Hollis Williams and by a number of other speakers, but he was afraid he was not in a position to say whether engines should be allowed to run at maximum r.p.m. for climbing or not. At the same time it seemed to him that whatever stipulations were made purely from a test point of view, in times of emergency if the pilot knew he could get some more " horses " out of his engine and so score a tactical advantage in aerial warfare, he most certainly would do so whatever the book of rules might say as regards peace time tests.

The greater advantage of the variable pitch airscrew when the speed range was large had been emphasised by Senor Cierva, who suggested that a large increase in static thrust would be very useful in the case of the autogiro to enable it to take-off from small areas. He agreed that the V.P. airscrew offered greater advantages as the speed range increased, but more particularly, of course, when the increase was obtained by raising the top speed and not lowering the landing speed. He himself suggested that a logical conclusion to the application of the V.P. airscrew to the ordinary aeroplane was to use it as an effective air brake to increase the gliding angle and so emulate the autogiro characteristic of landing in a small area.

He was glad that Dr. Watts agreed with the view expressed in the paper that careful attention must be given to each particular problem before the question could be answered as to whether the variable pitch airscrew was worth while. Personally, he would always prefer to put the question in another form, viz., given aircraft X, and knowing the purpose for which it had been designed, was it worth while to put on a variable pitch airscrew? The solution to that seemed to him fairly simple. Dr. Watts had also suggested that the paper was rather optimistic. To a certain extent he must plead guilty because he had endeavoured as far as possible to show the maximum that might reasonably be expected by pitch variation; there might be difficulties arising in practice which prevented the maximum always being obtained, but, on the other hand, advantages had been mentioned by the speaker and others which had not been referred to in the lecture, such as the case of the multi-engine aircraft when one engine failed.

Air Commodore Cave-Browne-Cave had suggested that it might be desirable to formulate different engine tests in connection with variable pitch airscrews, and this again brought in the question of maximum r.p.m. versus normal r.p.m. In that connection he agreed with Mr. Hollis Williams that although normal r.p.m. might still be the limit for sustained ceiling climbs, etc., there were occasions, apart from maximum level speed, where maximum r.p.m. might be justified; just as one was allowed to use increased boost pressure in the case of supercharged engines for take-off, why should one not be allowed to use increased r.p.m., although it might be necessary to revert to normal r.p.m. during the climb?

As regards Dr. Lachmann's interesting method of pitch variation, he did not know whether the speaker contemplated having flaps on the airscrew, but he had just received a note from the President to the effect that an airscrew was designed and built with a hinged flap in 1916 and it " bust " on test. Although that might be a correct statement of the facts in that particular case, he did not think Dr. Lachmann's idea should be ruled out entirely, because after all automatic pitch variation had yet to be developed really successfully; he believed, however, that this problem would be solved in the not too distant future.

He agreed with Mr. Mettam that some of the calculations in the paper had been based on a family of fixed pitch airscrews, but some recent full-scale work on pitch variation had supported the previous model work. Of course the results had yet to be confirmed by tests on an actual V.P. airscrew, but, as he had already remarked, he hoped this would soon be possible. He agreed with Mr. Mettam that small increases in top level speed near the ceiling were possible with a V.P. airscrew. He did not think that the mean take-off thrust when the basic pitch diameter was 1.5 would be much greater than that shown in Fig. 3 for a pitch diameter ratio of unity since the increase in static thrust as seen from Fig. 2 was not appreciably greater. He agreed that pitch variation in the case of tandem airscrews when one stopped would be a very marked advantage.

It had been remarked by Mr. Griffiths that additional weight above the 80lb. mentioned in the paper might be rendered necessary to maintain the same standard of engine reliability when rotating at maximum r.p.m. He did not quite see why for take-off or short periods of climb the engine rotating at maximum r.p.m. would be less reliable, apart from cooling considerations, than in level speed at maximum r.p.m., which was already permitted for short intervals under the existing regulations. He was interested to hear that in America it was usual, in the case of fixed pitch airscrews, to limit the r.p.m. in level flight to 5 per cent. above normal; if this were a full throttle design criterion then of course pitch variation would give greater advantages for climb at normal r.p.m. than that obtaining under the design procedure adopted in this country.

The fact that the advantage to be gained from the variable pitch airscrew depended on the increased r.p.m. and changes in airscrew efficiency mattered but little had been quite rightly pointed out by Captain Barnwell. That was definitely

so in the climbing performance, but it was not quite true when one came to consider some other items of performance, *e.g.*, range, where he had found that the decrease in airscrew efficiency almost nullified the advantage of decreased consumption as the pitch increased.

In reply to Captain Barnwell's first question, he did not mean to imply that the climb performance curves with the fixed pitch airscrews in Fig. 1 were not applicable to gear-driven supercharged engines. They were, in fact, based on the assumption that up to the supercharge height the torque remained constant and then decreased in a similar manner to the normally aspirated engine; climb curves closely resembling this form are normally produced in practice by aeroplanes with supercharged engines. The estimation of the increase in climb due to pitch variation is, however, over-estimated in the case of the gear-driven supercharger, since it was assumed that the power required to drive the compressor remained constant as the r.p.m. increased, whereas actually the power absorbed increases at the higher rotation rate. As explained in the lecture little is known about the precise form this variation will take, but it has been estimated that when taken into account the improvement of climb will be about half that shown in Fig. 1.

The assumption that when gliding in to land the airscrew will rotate in the neighbourhood of zero torque was based on the fact that under static conditions on the ground it is usual to arrange the " idling " throttle stop to be adjusted to allow the engine to develop just about sufficient power to overcome the motoring losses.

Mr. Capon has emphasised the dependence of the advantages of pitch variation on the pitch diameter ratio of the original airscrew. He thought it was particularly unfortunate that the tests carried out in this country to demonstrate the improvement to be gained by a V.P. airscrew had been made on aircraft with low pitch airscrews where no appreciable gain would be anticipated.

Mr. Gordon England has proposed certain definitions to differentiate between the various types of " propellers " in which the blade angle is adjustable. I prefer to adhere to the definition laid down in the British Standard Glossary of Aeronautical Terms, namely, " Variable pitch airscrew—An airscrew whose blades are so mounted that they may be turned about their axes to a desired pitch while the airscrew is in rotation. Note.—This term is not to be used for an airscrew whose blades are adjustable only when stationary." I think it is usual to refer to this latter type as an adjustable pitch airscrew. My sub-division of V.P. airscrews into two main types then follows from the above definition.

With regard to manual control of airscrew pitch during take-off, I suggest that any additional control requiring the attention of the pilot during the take-off manœuvre is to be avoided and hence automatic pitch variation should be aimed at.

For the sake of simplicity the direct comparison made between the variable pitch airscrew and variable gear airscrew did not include the weight factor of either. I dealt with the effect of increased weight of the variable pitch airscrew in the early part of the paper and a similar effect would of course be applicable to the variable gear airscrew.

I agree with Mr. Gordon England that I have not touched on all the possible uses of a variable pitch airscrew, but have dealt mainly with the more important applications to a normal or general purpose aircraft, whether military or commercial. Each particular problem must, however, be treated on its own merits to establish the precise advantage to be gained by pitch variation.

I agree with Mr. Walker that the variable pitch airscrew will be of particular value to heavily loaded high speed commercial aircraft in improving their take-off and initial rates of climb. At present, however, the speed range of British aircraft of this type is such that in general only moderate airscrew pitch diameter ratios are used, and until the top speed is increased the full advantage of pitch variation

will not be felt. The use of the variable pitch airscrew as an air brake will, I think, also be of considerable value for increasing the gliding angle of such aircraft for landing.

I was interested to hear of Air Commodore Chamier's flying experience with variable pitch airscrews in America and to learn that he had observed a marked improvement in take-off and climb. Any comparison of level speeds should, I think, be based on constant throttle setting; it is clear that as the throttle is opened the engine torque will be increased and this may lead to an increase in power developed in spite of a reduction in rotation rate as the pitch is increased. Except in the case of long range flight where the fuel load is a large proportion of the total load I do not think that pitch variation will increase the maximum range appreciably, although the range at high speeds may be improved.

THE C.I. ENGINE AS THE RIVAL OF THE PETROL ENGINE

BY

C. B. DICKSEE, A.M.I.MECH.E., M.I.A.E.

(*Lecture read before the Yeovil Branch, November 16th*, 1933. *Abridged.*)
In the chair: CAPT. A. S. KEEP.

(Captain KEEP, in introducing the lecturer, referred to the fact that he was a well-known authority on the subject with which he proposed to deal, and that he had very kindly come down from the A.E.C. to describe some of the problems connected with the high speed compression ignition engine as a rival of the petrol engine.)

The petrol engine has become so firmly established as the motive power for aircraft, automobiles and small vessels that a short while ago it would have seemed almost impossible that its supremacy could be challenged. It is no exaggeration to say that it was the petrol engine which made aircraft possible, while on the road, despite the fact that the steam engine is fundamentally more suited for traction work, the petrol engine has practically ousted its rival from the field. Even for the heaviest vehicle, where, owing to cheap coal, the lower running cost at one time gave the steam vehicle an advantage, the petrol engine is nearly universal, while at sea, for launches and small craft, the steam engine has practically disappeared.

No matter what the service may be, if we ignore questions of personal prejudice, it is the suitability for the service in question, coupled with the operating cost, which decides for or against any particular prime mover. Apart from bulk and weight there is no reason why any one form of internal combustion engine should be any more suited to a particular purpose than any other, and, other things being equal, it follows that the one which offers the lowest operating cost will be the one selected. Hitherto, considered as a means of locomotion, the aggregate advantage of the petrol engine far outweighed those of any other form of internal combustion engine, the balance in its favour having lain very heavily on the side of bulk, weight and initial cost.

Now, however, a new form of internal combustion engine has made its appearance and is challenging the supremacy of the petrol engine for heavy vehicles and small marine engines, and already there are signs of activity in the aircraft field. This engine is the compression ignition engine which can claim a tremendous advantage on the grounds of fuel cost reduction. The wonderfully low fuel consumption of the Diesel engine has for a long time been the envy of the small high speed engine builder, but the weight, size and low speed of the Diesel engine proved an effective bar to its intrusion into the field where a compact and light prime mover is essential. The lowness of the cost of the fuel and the small consumption have, however, remained as a continual spur to the imagination of engineers, and have resulted in a development of which we are now seeing only the beginnings and which cannot but have a far-reaching influence upon almost every form of transport. Running on a fuel which, at the moment, is only about one-third the price of petrol, and utilising only about one-half to two-thirds of the quantity for the same amount of work, the compression ignition engine offers a means for effecting a substantial reduction in operating cost which cannot be approached by any other means. It is therefore little wonder that for service

where fuel cost is one of the chief items in operating cost, operators are only too anxious to take advantage of the saving offered. Two other advantages are claimed, namely, that the fire risk, which is ever present with petrol, is practically eliminated by the compression ignition engine, and that the ignition apparatus, by far the most fruitful source of trouble with the petrol engine, is dispensed with. How much the latter two advantages count depends largely upon the way in which the individual operator looks upon them.

Immunity from ignition troubles is an undoubted advantage, especially in the air and on the water, but it must be remembered that although we have eliminated the ignition apparatus and also the carburettor, we have replaced them by the injection device, and unless this is less prone to trouble than that which it supplants, we have but exchanged one set of troubles for another. While the injection apparatus is not entirely free from trouble, any more than is any other product of human inventive genius, yet, short as is the history of the high speed engine, it has proved itself to be extraordinarily free from trouble when designed and constructed by a competent concern. It cannot, however, be too strongly emphasised that accuracy of workmanship to a degree unknown in any other part of an internal combustion engine is called for if the injection apparatus is to function satisfactorily.

The word " performance," as applied to an internal combustion engine, is an all-embracing term which may mean much or little, according to the understanding or intention of the user. Broadly speaking, it is used to express the all-round suitability of any given engine for a given service, and is a thing to which a numerical value cannot be given, in fact, personal ideas enter into the question to no small extent. Every service has its own particular set of requirements which result in a different value being placed on each one of the many factors which contribute towards the final result. The chief of these factors may be taken as:—

Weight.
Bulk.
Dependability.
Cost of original plant.
,, operation.
,, maintenance.
Adaptability.

Of these factors, only the last calls for any explanation. By " adaptability " is meant the ability of the engine to do the particular job for which it is intended. This, to some extent, is also covered by " bulk." Thus, for example, the producer gas engine, despite its undoubted cheapness in operation, has so far resisted all attempts to adapt it satisfactorily to road haulage and marine purposes, and no one has even attempted to apply it to aircraft, while the petrol engine, despite the fact that it, in common with all other internal combustion engines, suffers from a serious defect in the matter of starting under load, has been successfully adapted to road haulage.

An outstanding advantage in one direction will nearly always allow some latitude in another, or should some disadvantage exist and no latitude be permissible, the problem will be attacked, and the attack persisted in until success is attained if the advantage to be gained is sufficiently great. This has proved to be the case with the compression ignition engine. The savings in operating cost promised by the successful development of an engine suitable for transport work were tremendous, but at the outset the off-setting disadvantages were very great. The first engines of this type to be developed were stationary engines and these were slow, the bulk and weight were great and the first cost therefore high, although the cost was reduced somewhat by the fact that our old friend cast iron entered largely into their construction, thereby contributing not a little to their bulk and weight. Early efforts to reduce the bulk and weight by an increase in

speed reacted unfavourably on the efficiency and also on the dependability and therefore the cost of maintenance. The prize which awaited the solution of the problem was, however, sufficiently great to encourage both the manufacturer and the user to persevere, and as the result of their persistence, the compression ignition engine has been brought to such a pitch of perfection that it is already an established fact in the marine and the heavier road transport field and it can only be a question of time before it becomes established in the air for some types of machine.

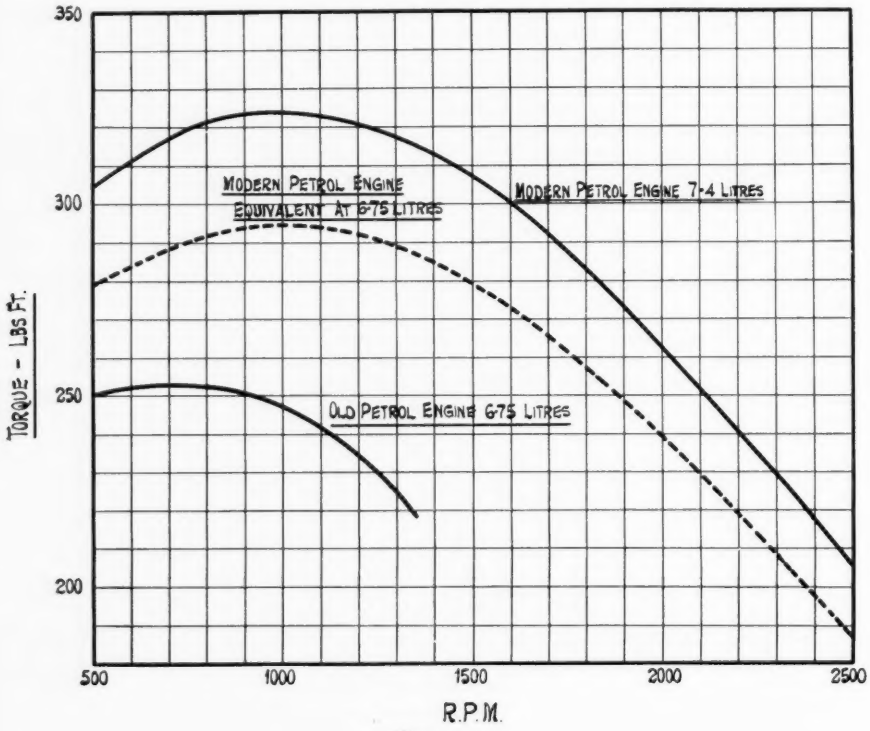


FIG. 1.

The adaptation of the compression ignition engine to automobile work has revived to some extent the old controversy as to the relative merits of high and low speed engines. This argument has practically ceased to exist in so far as petrol engines are concerned, and the high speed engine is now almost universal both for private and commercial vehicles. In making this statement it is not intended to suggest that large commercial engines are commonly operated at the rotational speeds which are now general for small private vehicle engines. The phrase " high speed " is a relative one in so far as revolutions per minute are concerned, although when considered in terms of piston speed, there is little to choose between the private car and the commercial vehicle engine.

Fig. 1 shows the torque curves of two petrol engines built by the author's firm, one from an engine dating from some ten years ago with a capacity of 6.75 litres and the other from an up-to-date design of 7.4 litres. Both of these engines are commercial vehicle engines, and used for both goods and passenger

work. The difference between these two is striking and shows the general trend of development during the past decade and gives a good idea of the problem which confronts the compression ignition engine in endeavouring to compete with the petrol engine.

The high speed compression ignition engine has thus made its appearance in the field at a time when the high speed petrol engine has become the established type for all classes of automobile and when after some forty years of intensive development the petrol engine has been brought to a very high pitch of perfection, both mechanically and thermally. In the air, the high speed engine is, of course, essential.

Much that we have learned during the development of the petrol engine has been of inestimable value to us in our efforts to bring the newcomer up to the same pitch of perfection as has been reached by its rival. This is notably so in the case of materials; all the light alloys and high tensile steels which have been produced to meet the exacting demands of the high speed petrol engine have been at our disposal, while all the knowledge gained in the study of rapidly moving mechanisms has been equally valuable. Many of the problems which faced us were, however, entirely new; they represented a terra incognita through which we have had to grope our way slowly and painfully and of which there is a large part still unexplored.

One of the most striking facts about the development of the high speed engine is the very small amount of assistance which has been obtained from the knowledge gained from the large slow speed engine, in fact, it is hardly an exaggeration to say that such knowledge has been a hindrance rather than a help and it is unquestionably a fact that the attainment of speeds which have any real pretension to be called " high " and of mean effective pressures which are anywhere near those obtained from petrol engines is entirely due to the efforts of the petrol engine designer rather than to the large slow speed Diesel engine designer.

To find a permanent place in any field now occupied by the petrol engine, the compression ignition engine will have to fulfil all the requirements of the particular service in a manner which ultimately does not fall far short of that achieved by its rival. At the moment, the tremendous saving in fuel cost obtainable with the compression ignition engine gives it an advantage which is sufficient to make road transport operators overlook certain shortcomings and has made them very patient with the troubles which have attended the early stages of this, as every other, new development. Ultimately, however, we shall be called upon to reach in every respect the standard set by the petrol engine, especially so in the case of speed. How much latitude we shall be allowed will depend partly on the nature of the service and partly on the advantages we offer.

For example, in the air we can afford to sacrifice very little in exchange for the elimination of the fire risk. For military purposes the pilot will not sacrifice even a small part of the performance of his machine for freedom from fire risk. Performance counts first, last and all the time, as it is useless to eliminate the fire risk if by so doing we place the machine at a disadvantage to an enemy who has preferred to keep his fire risk and his performance. In the case of civil machines, some more latitude is allowable, but even here we cannot afford to lose too much of our useful load. In the air, the saving in fuel cost is not so great as on the road on account of the better fuel consumption commonly obtained from aero engines. The strenuous conditions in the air, assisted by special circumstances which do not obtain on the ground, have resulted in very low fuel consumptions. It is true that in many instances the basic cost of the fuel is greater, but unless we develop the compression ignition engine to a point comparable in all respects with the petrol aero engine, it will be only in special cases when we shall be able to compete with petrol in the air.

The earlier compression ignition engines produced for vehicles, although termed high speed, were anything but that, having a maximum speed of only 1,000

to 1,200 r.p.m. This, although perhaps high when considered in terms of marine and stationary engines, was no more than that attained by the petrol engine in the earliest stages of its development as a means of transport, and it is perhaps as well that they originated on the continent where, owing to the fact that 1,500-1,600 r.p.m. is still a not unusual speed for commercial vehicle engines, this disparity in speed was not quite so marked as would have been the case in this country. Inadequate as these speeds were, they served to prove the very real saving that the use of this type of engine provides and thus encouraged engineers to continue their attempts to improve the performance.

The service demanded of the modern commercial vehicle engine is of a very exacting nature, particularly in this country where artificial restrictions as to vehicle dimensions and weight, and the magnitude of the taxation imposed, add materially to the designers' difficulty. When the overall length of the vehicle is limited, it is obvious that the space occupied by the engine becomes of great importance. With the maximum length of the vehicle allowed by the law, the maximum amount of space for pay load is provided by placing the driver alongside the engine. This expedient automatically fixes the maximum length which the power unit should occupy, namely, the minimum length which is required to accommodate the driver. Any increase on this length means a corresponding reduction in the useful length of the vehicle.

The question of weight is equally important. The maximum legal weight of a fully laden vehicle is 10 tons on four wheels and 12½ tons on six wheels for passenger vehicles, and 12 tons on four wheels and 19 tons on six wheels for goods vehicles. The total weight of the unladen vehicle therefore directly influences the amount of pay load which can be carried. In addition, the taxation is arranged in steps of one ton at a rate of £20 for each additional ton or part of a ton. An increase in the weight of the engine may therefore result in an additional £20 p.a. in tax in the case of vehicles which are less than the maximum prescribed by law.

It has become common practice to classify engines in terms of horse-power. This is somewhat misleading for vehicle engines since, although it is the maximum horse-power which determines the maximum speed of the vehicle on the level, it is the maximum torque which governs the hill climbing and acceleration. Both torque and horse-power are, of course, dependent upon the product of the volume of the cylinders and the brake mean effective pressure, but the maximum values of each are usually developed at widely different speeds. To obtain the same results from two different engines in the same vehicle, the product at any given speed of the mean effective pressure and the volume must be the same in each case. That is to say, if the mean effective pressure is increased, the volume of the engine can be decreased in direct proportion to the increase in mean pressure and vice-versa. In the latter case the overall dimensions of the engine and therefore its weight will be increased. The weight of a petrol engine of any given type is roughly proportional to its cubic capacity, but in the case of the compression ignition engine, owing to the greater maximum pressures which are general, the weight tends to increase at a somewhat greater rate. In petrol engines the sections of most of the heavier parts, such as cylinders, crankcase, etc., are determined very largely by foundry and manufacturing consideration. The higher maximum pressures of the compression ignition engine, however, may call for additional material, and this is particularly the case with the larger engines which are necessary when a low mean effective pressure is developed. In these engines a lower mean effective pressure does not necessarily mean a lower maximum pressure; often the reverse.

To obtain flexibility of the vehicle as a whole, a speed range as wide as possible is required from the engine. The high road speeds associated with modern vehicles demand a high maximum engine speed, and failure to obtain this entails additional gear changing and also a larger engine with added weight.

To make the case quite clear, let us take an actual example of a coach, the particulars being as shown in Table I, and the engine torque that already shown

TABLE I.

Gearbox ratios,	4th	...	1.0 : 1.
,,	3rd	...	1.66 : 1.
,,	2nd	...	2.80 : 1.
,,	1st	...	5.16 : 1.
Axle ratio ...	...	...	6.25 : 1.
Gross weight	...	...	10 tons.
Effective tyre radius		...	18in.
Rolling resistance	...	...	50lbs./ton.
Frontal area	...	...	70 sq. ft.

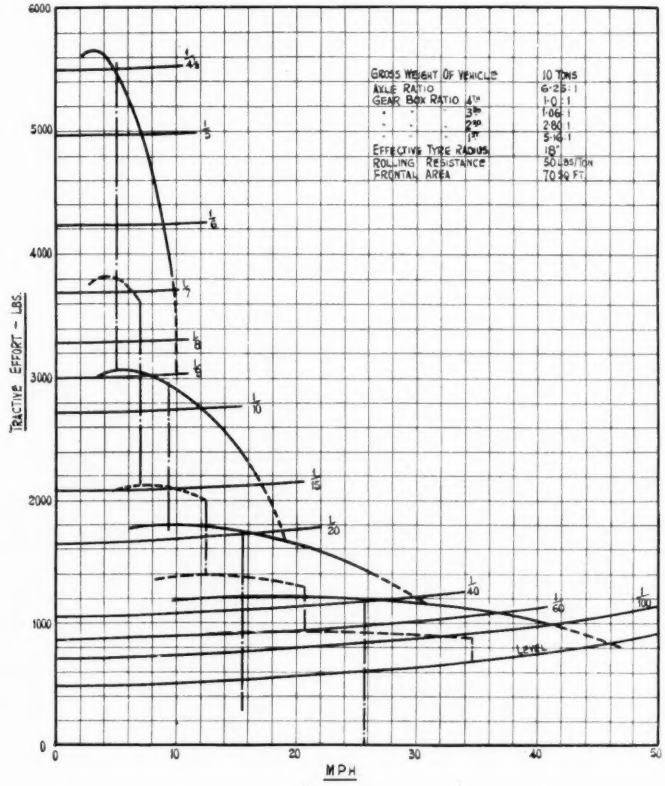


FIG. 2.

in Fig. 1 for a modern high speed engine. The performance curve for such a combination is shown in Fig. 2. From this curve it will be apparent that the vehicle will have an all-out speed on the level of somewhere about 46 m.p.h. in top gear and will easily reach 30 m.p.h. in third. The gradients, and the speeds at which they can be negotiated on the several gears, are also shown. At an engine speed of 2,000 r.p.m., a quite normal cruising speed to-day, road speeds

of 34.5, 20.8, 12.3 and 6.7 m.p.h. will be attained on the several gears. If now we place in this vehicle an engine which has precisely the same torque curve, but which has a maximum speed limited to 1,500 r.p.m., the maximum road speeds will be reduced to 25.8, 15.6, 9.2 and 5.0 m.p.h., and the performance of the vehicle as a whole will suffer very considerably. By far the most serious handicap is the loss of speed when in indirect gear, as the speed on hills and the possibility of changing down in order to accelerate for overtaking are both so much reduced that the average time for a given journey will be greatly increased. In the case of the compression ignition engine, this limit in speed is generally imposed by a governor in order to prevent the engine from being operated at speeds at which the combustion conditions are unsatisfactory. This governor is usually designed to operate fairly quickly after a certain speed is reached and as the result the upper end of the torque curve will fall more or less abruptly as indicated in Fig. 2. This means that on each gear anything to the right of this line in Fig. 2 is lost if the engine cannot be operated at speeds greater than 1,500 r.p.m. Let us now assume that while using the low speed engine we wish to attain the same road speeds as were given by the high speed engine at 2,000 r.p.m. To do so will necessitate changing the axle ratio in the ratio of the two speeds. Thus, $G = 6.2 \times 1{,}500/2{,}000 = 4.65$. This will, of course, reduce the vehicle climbing ability in like proportion, as shown dotted in Fig. 2, and will result in a much greater use of the gearbox to the discomfort and fatigue of the driver, additional annoyance to the passengers and to the detriment of the fuel consumption. Also, the tractive effort available in excess of that required to propel the vehicle at any given speed is correspondingly reduced so that the acceleration will thus be much lower. In order to obtain the same vehicle performance with a low speed as with a high speed engine, it is necessary not only to change the axle ratio, but also to increase the size of engine in the ratio of the two speeds. The torque curve shown in Fig. 1 was obtained from an engine having a swept volume of 7.4 litres, if therefore the maximum speed is limited to 1,500 r.p.m., not only will the axle ratio have to be changed to 4.65 : 1, but the engine size will have to be increased from 7.4 to $7.4 \times 2{,}000/1{,}500 = 9.85$ litres if the same road performance is to be obtained as that which is given by the 7.4 litre engine running up to a maximum speed of 2,000 r.p.m. Some adjustment in size may be possible to allow for the difference in torque produced at these two speeds, but in all fairness, it must be stated that an engine which had a speed limit of 1,500 r.p.m. would suffer some fall in torque as this speed is approached, its torque curve, although covering a narrower speed range, would in fact have a form similar to that shown for the high speed engine over its own range of speed. It follows, therefore, that with a low speed engine we are faced with the problem either of sacrificing performance in one direction or another or of increasing the size and therefore the weight of our engine and the space it occupies if the performance must be maintained. It is a cardinal point, often overlooked, that you cannot compensate for any lack of engine performance simply by juggling the gear ratio.

The foregoing shows very clearly the absolute necessity of developing the compression ignition engine to a point where it is really comparable with the petrol engine not only in speed but also in output per unit volume at any given speed. This is not to say that extremes of speed such as are now reached by small petrol engines must be reached by the compression ignition engine, but that the speeds which are common to-day for large commercial vehicle engines must be obtained. At the moment, the savings which accompany the use of the compression ignition engine are such that many operators are prepared to accept a quite considerable loss in vehicle performance, particularly so in cases where older vehicles are being re-engined. This is all to the good in helping us to get the newcomer established, but we must not let matters rest there. The present fortunate conditions will not last for ever. Already there are signs that the Chancellor of the Exchequer has his eye on the savings, and it may not be long

before further taxation will tend to reduce them. If this happens the loss in performance will no longer seem so insignificant. When all is said and done, the loss in performance means either reduced mileage and/or reduced carrying capacity, any of which means reduced earning capacity. Under these circumstances, something nearer the performance of the petrol engine will be demanded, and must be forthcoming, if the compression ignition engine is to find a permanent place in the road transport field.

The author's firm have recognised this from the first and have put forth every endeavour to improve both the speed and the output. When some five years ago we first began to look into the question, 1,400 r.p.m. was about the highest speed reached, while a maximum of 75lbs. sq. in. brake mean pressure was the best obtainable, and even at that low figure the exhaust colour was by no means free from reproach.

At the same date, the commercial vehicle petrol engine was developing 100 to 105lbs. sq. in. maximum brake mean effective pressure, reached its maximum power at a speed of about 2,200 to 2,500 r.p.m. and was frequently operated at speeds in excess of 3,000 r.p.m. for short intervals and for long periods at speeds of 1,800 to 2,000 r.p.m. or more. The gap between the performance of the two engines was thus pretty wide and the technical knowledge which was necessary to enable us to bridge the gap was of the scantiest description.

The whole secret of improved performance lies in improved combustion, both speed and mean effective pressure depending directly upon the rapidity and completeness of combustion. It might reasonably be assumed that since the efficiency of the compression ignition engine is greater than that of the petrol engine, the mean effective pressure developed, and therefore the output, should be correspondingly greater. The brake mean effective pressure of any internal combustion engine will be given by the following equation:—

$$P = W \times E \times 12$$

when P = B.M.E.P. in lbs. sq. in.
W = energy in foot lbs. per cu. in. of the charge.
E = the brake thermal efficiency.

The value of W when the chemically correct mixture is used may be taken as 45 ft. lbs. per cu. in. at N.T.P., and taking the absolute volumetric efficiency as 80 per cent., the net value in the cylinder will be 36.0 ft. lbs. cu. in. Under these conditions a petrol engine which has a brake thermal efficiency of 25 per cent. will develop a B.M.E.P. of $36.0 \times .25 \times 12 = 108$lbs. sq. in., nearly.

Taking the brake thermal efficiency of the compression ignition engine as 30 per cent., we might expect to obtain $36.0 \times .30 \times 12 = 130$lbs. sq. in., which, however, is unfortunately not the case.

The answer lies in the difficulty experienced in utilising the whole of the available air and we are thus unable to introduce sufficient fuel to enable us to reach this value of 36 ft. lbs. per cu. in. The power output of any internal combustion engine depends directly upon the amount of air we are able to consume within it in a given space of time. Thus, taking the figure of 75lbs. sq. in. B.M.E.P. mentioned earlier on, it will be evident that if under given conditions we should have developed 130lbs. sq. in., but actually develop only 75lbs. sq. in., we can only have consumed $75/130 = 57.5$ per cent. of the available air. To develop a B.M.E.P. of 108lbs. sq. in. as deduced for the petrol engine it would be necessary to consume $108/130 = 83.2$ per cent. of the air if the efficiency remains at 30 per cent.

The difficulty in utilising the whole of the air is due to the combustion system which is employed. In the petrol engine, where a substantially homogeneous mixture of fuel vapour and air is used, there is no difficulty in utilising the whole of the available air or indeed in burning mixtures which contain more fuel than the available air can consume. In fact, it is much easier to make the

engine run steadily when an excess of fuel is present than when an excess of air is present. A far wider range of usable mixtures exists on the rich side of the chemically correct mixture than on the lean side.

In the case of the compression ignition engine, no fuel is admitted until just before the moment when combustion should start. Under ideal conditions ignition would take place the moment injection commences, but, owing to a number of physical difficulties, a certain amount of delay in ignition takes place, a phenomenon which provides one of the more difficult problems with which we have had to deal. The air and the fuel have to search each other out during the actual period when combustion is taking place, and under these circumstances it is not difficult to see that to utilise the whole of the available oxygen provides a problem of some magnitude.

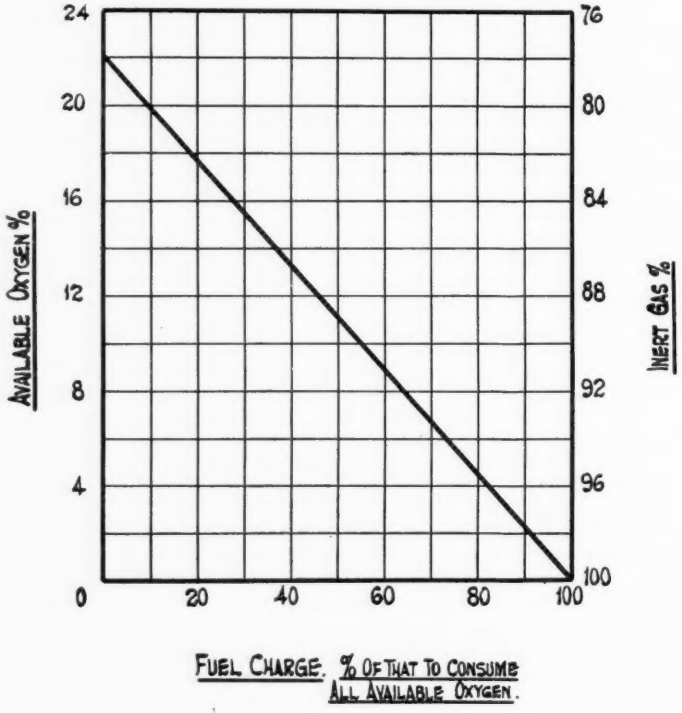


FIG. 3.

For the moment, let us assume that combustion keeps pace with the injection, that the whole of the oxygen is consumed, and also that pure air, undiluted by any residual exhaust gases, is contained within the combustion chamber. The first few particles of fuel to enter find an atmosphere which contains some 22 per cent. of oxygen, and thus have no difficulty in consuming all they require. As injection proceeds, however, the oxygen gets progressively more scarce (Fig. 3) until, by the time that, say, 80 per cent. of the fuel has been admitted, the atmosphere within the cylinder contains only a little over 4 per cent. of oxygen, distributed throughout a mass of inert gas consisting of a mixture of nitrogen, carbon dioxide and superheated steam. It is easy to see, therefore, that the remaining

20 per cent. of fuel will have considerable difficulty in finding this small remaining fraction of oxygen.

In actual practice the air is never quite pure since there will always be a certain quantity of residual exhaust gas present. The amount is, however, small, being only about 1/13 to 1/16 of the total volume, and as, in addition, it contains a certain amount of free oxygen, it does not seriously influence the results. The combustion, even during the early stages, will never keep pace with the advent of the fuel, and during the later stages it is not difficult to visualise a considerable lapse of time between the admission of a particle of fuel and its complete combustion. How nearly the combustion follows the injection has a very important bearing not only upon how much of the air can be used, but also how fast the engine can be run, and the ultimate thermal efficiency of the engine.

The efficiency of all heat engines depends upon the amount of expansion which takes place after the addition of the heat. In the case of an internal combustion engine the possible amount of expansion is governed by the ratio between the combustion chamber volume and that of the whole cylinder when the piston is on its outer dead centre. The effective amount of expansion depends very greatly upon how rapidly combustion proceeds. In the ideal heat engine it is assumed that combustion is instantaneous and complete and takes place at the inner dead centre. These conditions are not, however, realised in actual practice as combustion is never instantaneous and by no means always complete, although in this latter respect the compression ignition engine offends but little. As combustion is not instantaneous it follows that it cannot all take place at the inner dead centre and as, for obvious reasons, only a very small percentage can be allowed to take place before the inner dead centre is reached, part at least must occur after the piston has commenced its outward stroke. The amount of expansion which the gases undergo after having received the heat from any fuel which is burnt after the piston commences its outward stroke is something less than the maximum possible for the set of conditions governing the engine, and the efficiency obtainable from any such fuel is correspondingly reduced. The efficiency of the engine as a whole is the summation of the efficiency derived from each small particle of fuel, and it follows that a combustion process which carries on down the expansion stroke must result in a decreased efficiency for the engine. It may, perhaps, not be amiss to mention that even in a petrol and a gas engine, under the favourable conditions provided by a homogeneous gaseous mixture, the combustion is by no means completed when the expansion stroke commences, and is frequently incomplete by the time the expansion stroke is finished, as is indicated by the flames which are frequently seen at the exhaust ports of such engines.

In the compression ignition engine, combustion is brisk enough during the early stages, but as the available oxygen gets progressively less and the search for it becomes more difficult, there is a tendency for it to slow up during the latter stages until a point is reached where, despite the presence of unused oxygen, and although further fuel may be supplied, it ceases entirely. Any fuel thus added will be broken up by the high temperatures, and the carbon particles powdered will appear a dense black smoke in the exhaust gases.

The question of obtaining a high specific output, a high efficiency and a high rotational speed are thus really a single problem and depend entirely upon the speed at which the combustion reaction can be made to take place and the completeness with which the air is used. Not only must the combustion reaction take place rapidly, but conditions must be so adjusted that the speed is a direct function of engine r.p.m. It will be obvious that if the speed of combustion bore no relationship to the engine r.p.m., but took place at some fixed rate, satisfactory conditions could only be obtained over a relatively narrow speed range; at low speeds the rate would be too great, while at high speeds the engine would tend to outstrip the combustion, and the efficiency would fall very rapidly. The old

idea was that the fuel was first vaporised, then mixed with the air and finally ignited by the heat of compression. This process postulated a fuel air mixture such as is used with a carburettor engine, and it is rather curious that, with the well-known troubles which result from the use of too great a compression in carburettor engines, engineers have failed to realise that any process which entailed the ignition by the heat of compression of a fuel vapour air mixture, would result in a much exaggerated form of the trouble occasioned by too high a compression in carburettor engines. It was held, and no doubt with some justice, that the speed of an engine which used such a process of combustion was of necessity low, and it is due to the automobile engineer, who, either from ignorance of it, or some other reason, ignored this dictum, that the speeds and outputs which are reached to-day have been made possible.

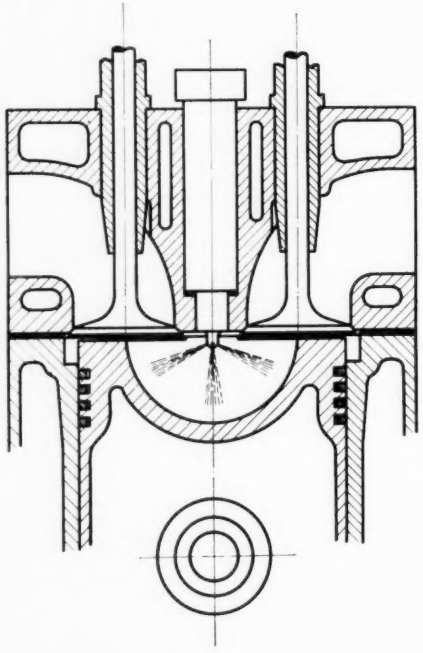


FIG. 4.

The actual process of combustion is something quite different, and is one which, with proper treatment, is capable of being speeded up almost indefinitely. What happens is something like this: The fuel is delivered into the combustion chamber in the form of minute globules which are travelling at a high speed through the air. After a short delay, during which they are absorbing heat from the highly heated and compressed air, they ignite and go flying through the combustion chamber like miniature meteorites. No intermediate vaporisation takes place. The velocity of their motion tears away the burned gases thus exposing an ever fresh surface to the air until, if conditions are right, they are completely consumed or, if conditions are not so well adjusted, they either come in contact with the combustion chamber wall or are extinguished for lack of oxygen. Such a process, it will be conceded, would appear to lend itself admirably to an increase in speed to almost any desired extent.

It should be necessary to increase only the relative speed between the fuel and the air to produce a corresponding increase in the combustion reaction. No matter how much the velocity is increased there will be no tendency to blow out this flame, because the air through which the globule of fuel is travelling is itself at a temperature above the ignition point of the fuel. There are, however, certain factors which make it a difficult problem to increase the speed indefinitely.

To obtain moderate speeds, up to about 1,200 r.p.m., it is sufficient to give motion to the fuel alone, and in engines of this type the combustion chamber is given a compact form and the fuel is admitted in the form of a number of fine jets designed to search out the combustion chamber as thoroughly as possible (Fig. 4). Conditions must be so adjusted that the bulk of the fuel is consumed during its journey from the nozzle to the far combustion chamber wall. Failure to do so is attended by a dirty and offensive exhaust.

Very excellent results are obtainable with the system if the maximum speed is moderate or in cases where, although the maximum speed is somewhat greater, the range of speeds over which the engine is required to operate is narrow. The difficulty lies in the fact that the spray and the combustion chamber must be very

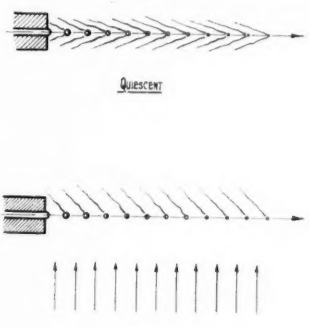


FIG. 5.

carefully adjusted to each other and that wide changes in speed upset the balance. A multi-hole spray is necessary in order to search out the whole combustion chamber volume as thoroughly as possible and at the same time to avoid overcharging any zone, since to do so inevitably results in a dirty exhaust. The atomising effect of the nozzles is obtained by the assistance offered by the small holes in the nozzle, a wide change in engine speed then results in a wide range in injection pressure and a corresponding change in atomising effect and in the character of the spray. This causes overcharging in some zones and undercharging in others and at the same time produces a tendency towards overpenetration at the higher speeds.

This difficulty is overcome by giving the air within the combustion chamber a swirling motion. The indiscriminate turbulence whch is so effective in petrol engines is quite useless in the compression ignition engine. The function of turbulence in a petrol engine is to distribute flaming particles throughout a uniform fuel-air mixture and thus promote a rapid inflammation of the whole mixture. This will be done most effectively by an indiscriminate turbulence which produces a thorough and continuous mixing of the gases during the combustion period. In the compression ignition engine what we require is to ensure that a steady stream of fresh air is brought into contact with the burning particle of fuel. To insure the complete combustion of a particle in the shortest possible space of time it is necessary to prevent the particle from entering a zone from which the oxygen

has already been removed, and the only means of ensuring this is to provide the air and the fuel with a well defined relative motion. To this end the air is given a rotary motion and the fuel is injected across the stream at right angles to this motion of the air. This ensures that each drop of fuel traverses gases of the

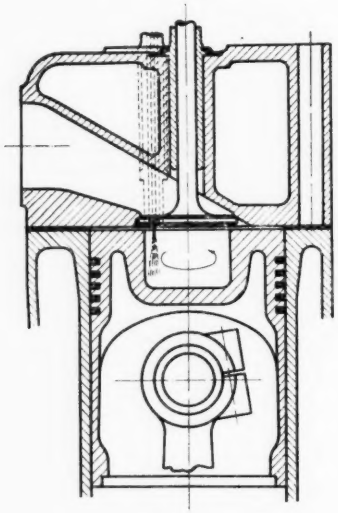


FIG. 6.

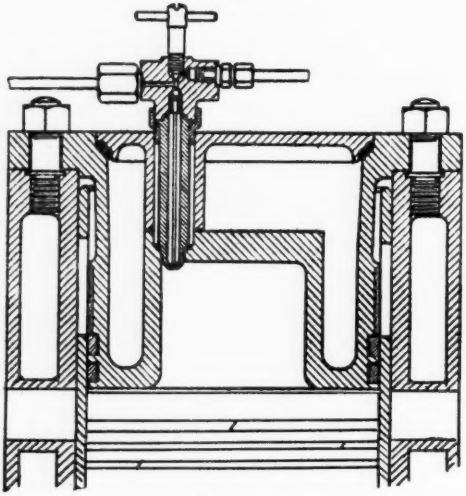


FIG. 7.

maximum possible purity and avoids the possibility of one fuel droplet following more or less directly in the path of its predecessor (Fig. 5), as is the case with this plain open combustion chamber with the gases in a more or less quiescent condition. There is, of course, a certain amount of indiscriminate turbulence in

almost any combustion chamber, due to the inflow of air during the suction stroke. This, however, as already pointed out, is of no direct benefit, and the engines wherein no attempt is made to produce a well defined movement of the air may for all practical purposes be considered as having the air in a quiescent condition.

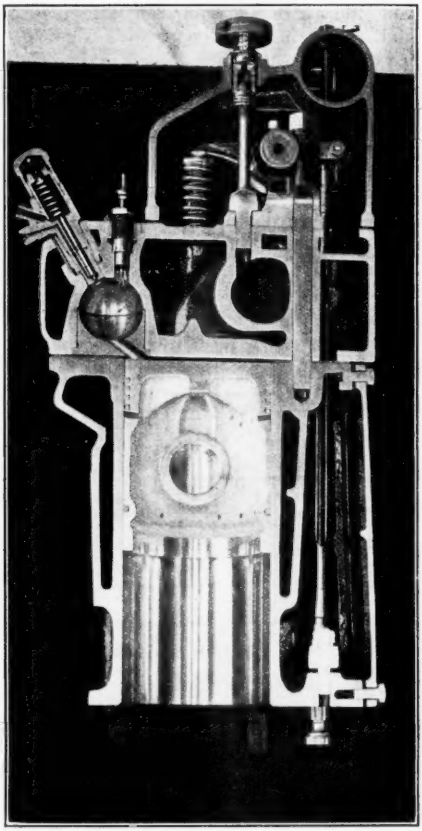


FIG. 8.

The swirling movement of the air may be obtained either during induction or during compression. When generated during induction, the air is made to enter the cylinder in a tangential direction by means of baffles or specially shaped ports (Fig. 6), and the combustion chamber is made somewhat smaller in diameter than the cylinder so that the speed of rotation is increased proportionally. The difficulty with this system is that the device adopted for producing the swirl offers a certain amount of resistance to the air flow and consequently, sooner or later, causes a loss in volumetric efficiency. An exception to this rule may be made in the case of the sleeve valve engine as developed by Ricardo; the ample port area which is possible with this type of engine and the ease with which the passages may be shaped to give the required direction to the air without causing restrictions makes it ideal for this purpose (Fig. 7).

To produce the swirl during the compression stroke avoids the above difficulty, although there is doubtless some loss of power at high speeds due to the energy absorbed in producing the swirl. In engines of this type, the air is forced out of the cylinder during the compression stroke into a separate combustion chamber. This combustion chamber is usually spherical in form and is connected with the cylinder by a passage which is arranged tangentially to the periphery of the combustion chamber so that the air on entering the latter assumes a rotating motion (Fig. 8). This method, which is also due to Mr. Ricardo, is most effective and enables speeds to be obtained which are at any rate equal to those which are normally used in every day service with large commercial vehicle engines, This is the system adopted by the author's firm, and although our engines are governed to a maximum speed of 2,400 r.p.m., speeds of well over 3,000 r.p.m. have been obtained under road conditions. As a point of interest it may be mentioned that it has been found desirable to limit the maximum speed of petrol engines when fitted to heavy goods models in order to avoid continual abuse by drivers. The chief reason for limiting the maximum speed of the compression ignition engine lies in the fact that as the maximum speed approaches

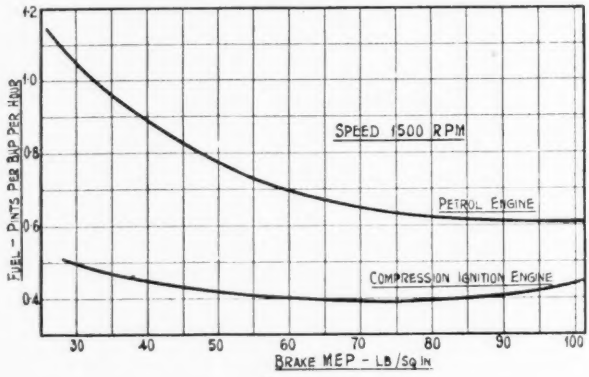


FIG. 9.

the point where the volumetric efficiency begins to fall off, the air alone is influenced, the quantity of fuel remaining unchanged, or indeed slightly increased, due to a rising fuel pump characteristic. The cylinder thus becomes overcharged and the exhaust turns black As it is impossible to ensure that this condition will never arise, a high speed governor thus becomes desirable in order to avoid the nuisance and waste that this condition would entail.

When used for automobile purposes the great saving in fuel consumption which follows from the use of the compression ignition engine depends not so much upon the difference in fuel consumption at full load as that which is obtained at fractional loads. The advantage which is obtained at fractional loads is even greater than that which is obtained at full load. The petrol engine, subject to any faults in carburation, is supplied with the same mixture strength at all loads. The maximum temperature of the cycle is thus substantially constant and, since the expansion ratio remains unchanged, the indicated thermal efficiency remains approximately the same for all loads. Certain changes do occur in maximum temperature, due to the increasing proportion of residual gases which are present at the smaller throttle openings and to several other causes, but the difference is relatively small. At any one speed the mechanical losses of the engine remain practically constant for all loads, and the net result is that the

thermal efficiency on a brake horse-power basis steadily decreases as the load decreases and the specific fuel consumption undergoes a corresponding increase.

In contradistinction to the petrol engine, the compression ignition engine draws in a full charge of air every cycle, the fuel alone is varied. The maximum temperature of the cycle thus decreases as the load decreases. This lower temperature means a lower specific heat, and the efficiency, measured on the indicated horse-power basis, consequently tends to increase. The decrease in specific heat is materially helped by the reduction in weight of carbon dioxide in the exhaust, it being the high rate of increase in the specific heat of this gas which is in great measure responsible for the lower efficiency at the higher temperatures of all internal combustion engines. A point which tends further to increase the indicated efficiency at low loads is that the combustion is completed earlier in the cycle

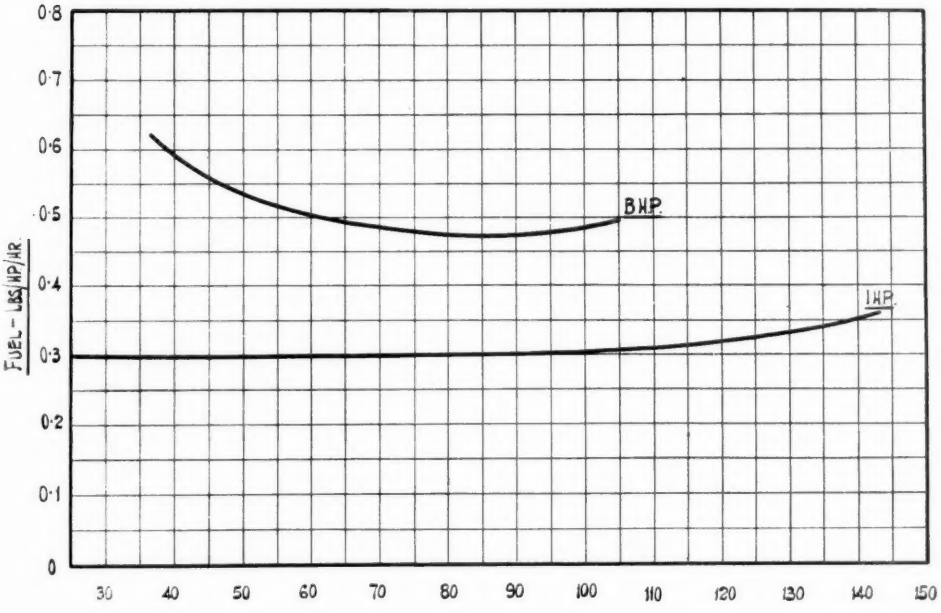


FIG. 10.

on account of the relatively greater quantity of oxygen present, and also because injection finishes sooner, the mean expansion ratio is thus increased with an obvious gain in efficiency. The gain in efficiency from these causes is sufficient to make itself felt on the brake thermal efficiency, and as the load is decreased from the maximum, the brake thermal efficiency at first actually increases and then remains substantially constant over a fairly wide range before the mechanical losses ultimately make themselves felt sufficiently to cause an upward trend in the consumption curve (Fig. 9). The steady decrease in consumption right down to no load, when measured on the indicator horse-power basis, is also shown on the diagram (Fig. 10), which is taken from a single-cylinder experimental engine which had a mechanical efficiency of only 73 per cent. at full load.

Fig. 11 shows the output obtained from the six-cylinder 115 × 142mm. 8.85 litre engine built by the author's firm, together with the fuel consumption. This consumption curve corresponds to the power given and represents therefore the full load consumption. At part loads the consumption is as shown in Fig. 12,

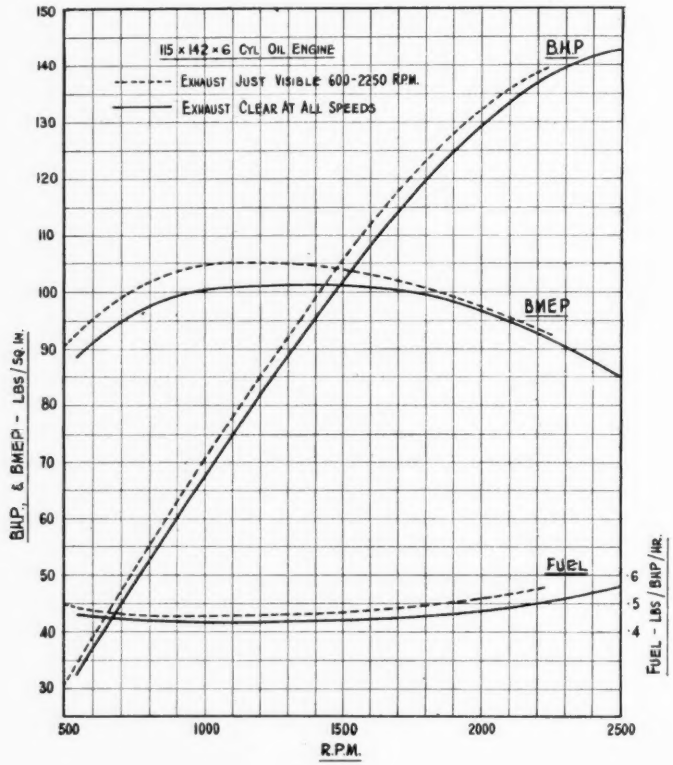
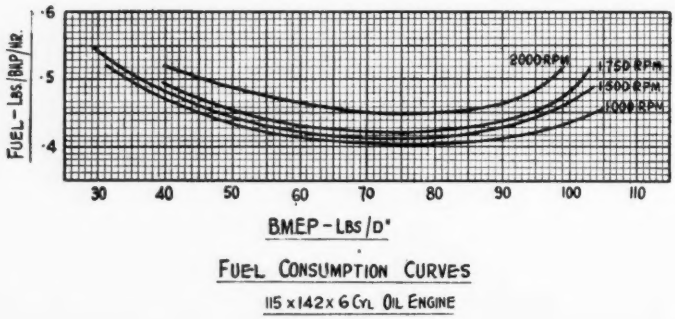


FIG. 11.



FUEL CONSUMPTION CURVES
115 x 142 x 6 CYL. OIL ENGINE

FIG. 12.

which illustrates very clearly the very flat nature of the curves. Fig. 13 shows the power curves of the compression ignition engine and the petrol engine, together with a curve which shows the output of the compression ignition engine reduced to correspond to the same swept volume as that of the petrol engine. This brings out very clearly how small is the difference between the two, and shows how much progress has been made during the past few years. The weight of this engine—complete except for dynamo, starter and flywheel—is 1,278lbs.,

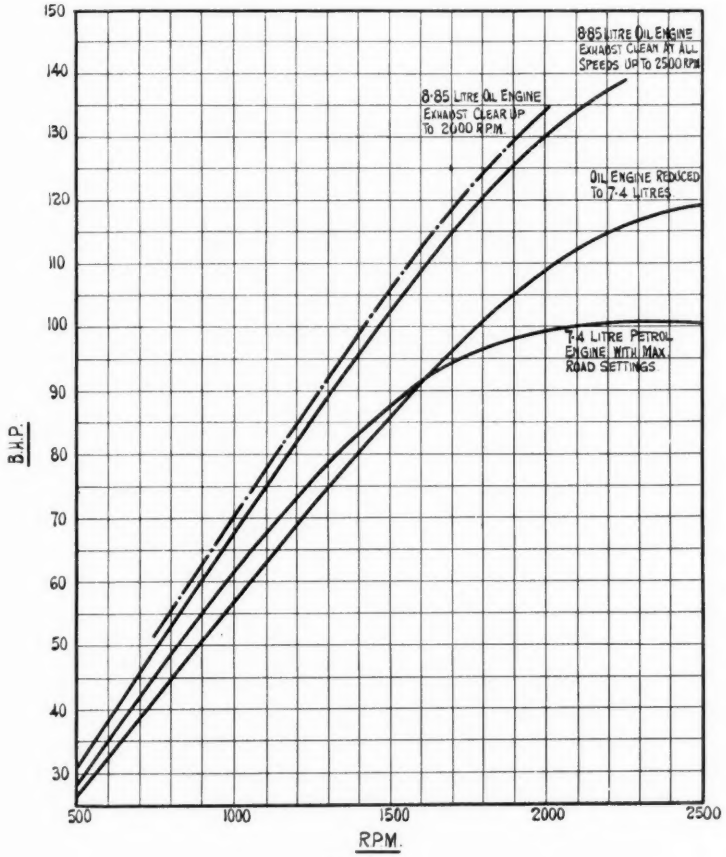


FIG. 13.

that of the petrol engine is 966lbs., working out at 13.7lbs. and 13.5lbs. per litre respectively.

Great as has been the improvement during the past five years, and despite the fact that we can equal the specific output developed by the petrol engine, it must not be forgotten that, as has already been pointed out, the specific output which we are entitled to expect should actually be greater. There is thus still something to accomplish.

The foregoing remarks have been based very largely upon the vehicle engine, but this problem is much the same for the aircraft engine. Weight is of far

greater importance in the air than on the road, so that the arguments as to the necessity of developing the output of the compression ignition engine up to that of the petrol engine apply with ever greater force. Owing to special conditions, and encouraged by the demand for smaller and even smaller engine weights, much higher compression ratios are used for aircraft petrol engines than can be

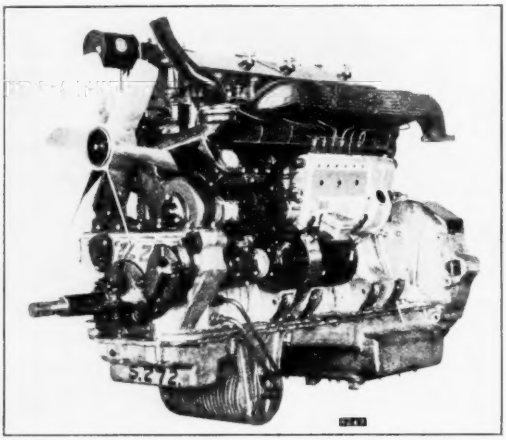


FIG. 14.

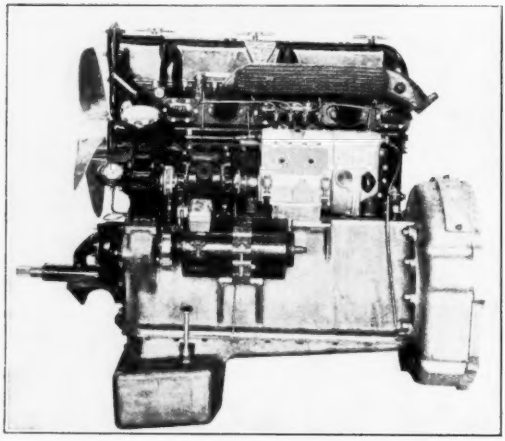


FIG. 15.

used on the road. As a result, brake mean pressures of 130 to 140lbs. sq. in. are developed on a fuel consumption which reduces considerably the advantages in this direction which can be claimed for the compression ignition engine. There is thus less chance of taking advantage of some of the saving in weight in fuel and tanks to allow a somewhat greater engine weight, and although a considerable saving in fuel cost can be made, the proposition is not quite so attractive

in this respect in the air as on the ground. It is therefore imperative to develop the compression ignition engine to a point when the output from a given volume is equal to that obtainable from the petrol engine, if aircraft operators are going to take a real interest in it. The author, however, has little doubt that this result will eventually be obtained and that the compression ignition engine will ultimately secure a place in the air. After the tremendous progress which has been made in the past few years, it would be a bold man who dared to assert that aircraft engine standard can never be reached.

FIG. 16.

Fig. 15 shows the four-cylinder engine, and Fig. 14 the six-cylinder engine built by the author's firm. The former is made with two sizes of cylinder which develop 70 and 90 h.p. approximately at 2,000 r.p.m., at which speed both these engines are governed.

The six-cylinder engine, which is governed at 2,400 r.p.m., delivers rather more than 140 h.p. at that speed. Fig. 16 will be of interest in that it shows the special streamlined saloon car built by Capt. G. Eyston fitted with the standard six-cylinder A.E.C. engine. In this machine he recently set up a world's record at Brooklands by establishing, under exceedingly adverse conditions, an average speed in both directions of 101.93 m.p.h. on the flying mile, and over the flying kilometre a speed of 104.86.

In conclusion, the author would like to express his thanks to the Associated Equipment Co., Ltd., for permission to publish information obtained during the development of their engines.

DISCUSSION

Capt. KEEP: Had any trouble due to wear on the injection pumps been experienced?

Mr. DICKSEE: No, unless a careless worker leaves dirt in the pump on assembling after cleaning, or if an operator fails to lubricate the timing device. Occasional failures have occurred due to broken pump springs, but on the whole the pumps have proved remarkably free from trouble.

Mr. PENROSE: Have sufficiently slow idling speeds been achieved?

Mr. DICKSEE: This depends on the governor and the weight of the flywheel used. The standard speed with the Bosch governor was of some 350 to 400 r.p.m. With the light flywheel which A.E.C. used this speed was quite satisfactory. If a heavy flywheel was fitted, the speed could be reduced to about 100 r.p.m., or less, if a governor suitable for such a low speed was fitted.

Mr. PENROSE: Some trouble in getting a sufficiently low idling speed has been found in aero engine practice.

Mr. DICKSEE: This he could understand, as it was due to the large cylinder size and the small flywheel, and he could see that it was quite a problem for aero engines.

Capt. KEEP: Had there been any trouble due to the use of such a high compression ratio as 16:1?

Mr. DICKSEE: No, about $13\frac{1}{2}$:1 is more usual with the open combustion chamber, but with the "swirl" type which he had described, and which was used by his firm, the higher compression ratio was possible, and advantageous for smooth running, and he felt that even with the open type a slightly higher ratio would give an improvement in this respect.

Mr. TAYLOR: Were heating plugs used to facilitate starting?

Mr. DICKSEE: Only when the engine has to be started from stone cold, such as when the vehicle has been left out all night, and in these conditions a pressure on the heater button for 15 seconds before pressing the starter button gives instant starting.

Mr. JACKSON: Has there been any trouble from heater plugs burning out?

Mr. DICKSEE: Not now, as the design is much improved, and unless the plugs are grossly abused they are satisfactory in service for very long periods.

Mr. ROBERTSON: Is a compression release device made use of for starting?

Mr. DICKSEE: No, they find starting easier without, as so much energy is absorbed in attaining the speed necessary before bringing the engine to full compression, and they find it better to do without this device. In cases where sufficient flywheel weight is provided to make hand starting possible, starting is most easily effected by rocking the engine to and fro once or twice and then giving a quick jerk to bring it over compression.

He admitted, however, that in the case of the six-cylinder engine with the light flywheel which is used therewith, hand starting is not practicable, and he referred to the fact that even the larger sizes of transport vehicle petrol engines are very difficult to start by hand. With the compression ignition engine he said that there was a zone probably ranging from 60 to 80 r.p.m. where it is harder to start than at either lower or higher speed.

Mr. HASLAM: Has the inertia starter been tried?

Mr. DICKSEE: Yes, they had tried a hand-operated one built by themselves, but which had been abandoned as it was not entirely successful. The Bosch Company were now making one electrically driven which should be successful and which it was hoped to test shortly.

Mr. JACKSON: Is there a bad spot as regards speed on starting if "glow" plugs are used?

Mr. DICKSEE: No.

Mr. JACKSON: Could one always start by hand with a compression ratio of 16:1?

Mr. DICKSEE: No, unless a heavy flywheel is used, or unless the engine is warmed after remaining in the open all night. This applies to all types of engine.

Mr. TAYLOR: Has there been any trouble due to loose bronze valve seats?

Mr. DICKSEE: Only on one occasion in connection with aluminium heads, although they had proved troublesome with cast iron heads.

Mr. PILLING: In comparing the fuel consumptions, have the possibilities of supercharging been considered?

Mr. DICKSEE: Yes, the compression ignition engine forms an ideal subject for supercharging. A small amount of supercharge, without any additional fuel, should result in an improved output with the full load fuel charge. By supercharging to half atmosphere a single-cylinder engine of the type built by the author's firm a B.M.E.P. of 185lbs. per sq. in. had been obtained. Allowing as much as 30lbs. sq. in. for driving the supercharger (which had been separately driven) meant a net output of 155lbs. sq. in. B.M.E.P., while with a multi-cylinder engine the net result should be quite a bit better. The "air swirl" type of engine seemed to lend itself to supercharging more readily than the open combustion chamber type. Supercharging the compression ignition engine tended to produce smoother running, whereas the reverse was the case with the petrol engine. The supercharged engine is the logical future development of the compression ignition engine.

Capt. KEEP: Has there been any valve trouble?

Mr. DICKSEE: No, with the RR50 alloy heads and aluminium bronze seats, valve seats had been found bright after 15,000 miles or more, although a slight mottling of the surface was found. With cast iron heads and seats the results were as good. The results obtained were, without question, far superior to those obtained with exhaust valves in petrol engines—in fact, exhaust valves were not a problem in the compression ignition engine.

Mr. RUSSELL: Do the Continental engines which use pump and atomiser pressures of 8,000 and 10,000lbs. sq. in. show a corresponding increase in wear and tear of the atomiser over that experienced by British manufacturers using a pressure of 2,000lbs. sq. in.?

Mr. DICKSEE: He had no information on that point. Their own atomiser troubles were negligible. The nozzle used was the pintle type, and many nozzles have been three years and upwards in continuous service.

Mr. PILLING: Has there been any trouble due to fouling of the nozzles?

Mr. DICKSEE: No trouble was experienced, as the pintle type was to some extent self-cleaning. The one used by the A.E.C. comprised an annular space surrounding a 2mm. pin, and resulted in 30° hollow cone of spray. This annular space ensured freedom from choking unless some large portion of foreign matter was present, in which case it would cause the injector nozzle to stick in the open position; apart from this advantage, this type of injector was easily cleaned. It was, however, not suitable for the open combustion chamber, which needs a hard spray, whereas the pintle nozzle gives what is called a soft spray, which, whilst it would be uncomfortable if felt on the hand, would be not more than that, whereas the multi-hole type of injector nozzle would project a jet powerful enough to bore a hole in one's hand.

Capt. KEEP: Has there been any trouble with the bronze seatings in RR alloy heads?

Mr. DICKSEE: No, providing they were put in correctly by heating the head in boiling water and making the seats .001 to .002 interference fit, and then screwed tightly home.

Mr. JACKSON: Was the lecturer not unduly hard in limiting the speed to 1,400 r.p.m. in the case of the open combustion type of compression ignition engine?

Mr. DICKSEE: No, in fact without some degree of swirl in the combustion chamber, he thought 1,200 r.p.m. was more nearly the limit if a decent m.e.p. was to be obtained. Engines giving a good m.e.p. are now built running at 1,700 r.p.m., but swirl is provided. Up to 2,000 r.p.m. has been claimed in some instances, but the m.e.p. is relatively low.

If an engine had to be designed for a definite speed, such as for stationary work in electrical generating units, then one could deal with 1,500 r.p.m. and about 75 m.e.p., but for road use we must get up to at least 90 m.e.p.

THE STRUCTURE OF TIMBERS IN RELATION TO THEIR USES*

BY

FRANK W. JANE, B.SC.(LOND.), F.L.S.

"The last thing I purposed to speak of, is, Those several Qualities of Timber or of Trunks, by which they are fitted for Mechanical Use. . . . The Visible Causes whereof are observable, Partly in the Structure of the several Parts; sc. the Insertions, Sap-Vessels and Aer-Vessels; as to the Number, Size or Position of any of them. And partly, in the Nature of the Parts; I mean such as is manifest to sense. According to our clear and distinct observing of all which Causes, we may understand, Wherefore any Wood is made use of for any certain purpose. And also, wherein fitly to apply it to further Use."

NEHEMIAH GREW, *The Anatomy of Plants*, 1682.

Almost without exception, wood of economic importance is obtained either from dicotyledonous or coniferous plants. In the trade timbers are classified as Hardwoods or Softwoods, the distinction depending not upon hardness, for there are many hardwoods much softer than the average softwood, but upon texture; the difference in texture depends upon differences in structure between dicotyledonous woods, or hardwoods, and those of conifers, or softwoods.

Coniferous woods have a relatively simple, homogeneous structure, consisting of fusiform cells, the tracheids (text-fig. 2*A*, tr.) lying in a vertical position, and separated at more or less regular intervals by sheets of cells, which take a radial course; these are the rays (*r*). The walls of the tracheids have bordered pits (*bp*) sometimes almost equal in diameter to the width of the tracheids. These pits usually occur only on the radial walls, although in some species they are found on the tangential walls as well. In a few conifers the tracheids have spiral thickening; this feature is probably seen at its best in the Yew (*Taxus*). The ray cells (*rc*) have simple pits (*sp*) on their walls; these pits vary in shape and position and are helpful in identifying woods. In a few genera another type of tracheid is met with, lying horizontally and associated with the rays (*r.tr*); these ray tracheids usually lie at the top and bottom of the ray, but are not infrequently situated between the ray cells. Like the vertical tracheids, they have bordered pits (*bp'*) on their walls, but these pits are small.

Most coniferous woods contain resin. This may occur in some of the tracheids, as in the Kauri Pine (*Agathis*), or in special resin cells amongst the tracheids: such cells are numerous in the Californian Redwood (*Sequoia sempervirens*) and in the King William Pines (*Athrotaxis*). In a few genera resin occurs in ducts or resin canals, which are spaces between the tracheids, lined with epithelial or secretory cells. Such resin canals, which are found in the Pines (*Pinus*) and Spruces (*Picea*), may take a vertical or horizontal course. If the latter, they always occur in a ray and alter its shape. The presence of these horizontal resin canals, their shape and the shape of the ray containing them are valuable aids for the identification of certain softwoods. When they do not contain resin canals the rays of softwoods are nearly always one cell wide in a tangential direction: vertically they may be short, only a few cells high, as in Cypress (*Cupressus*), or long, as in the Cedars (*Cedrus*).

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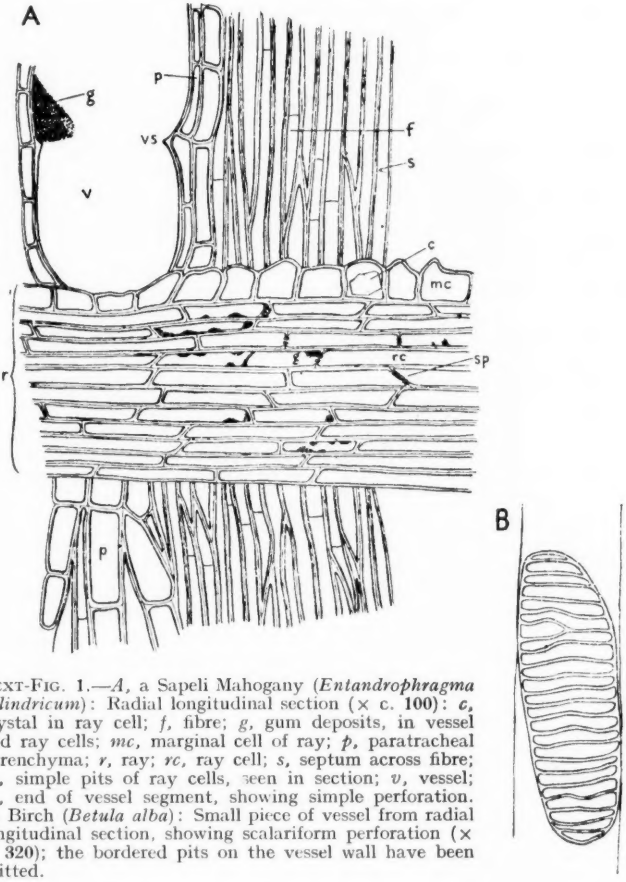
The structure of dicotyledonous wood (text-fig. 1*A*) is more complex. In place of tracheids there are normally at least three types of elements, vessels, fibres and parenchyma. Tracheids may also be present. The parenchyma cell (*p*) is either more or less cubical or is elongated vertically: its walls have simple pits. The vessels (*v*) are formed of a number of parenchyma cells, piled end on end, from which the horizontal or oblique end walls have disappeared more or less completely. In some plants a number of bars remain, and each vessel will then



TEXT-FIG. 1.—*A*, a Sapeli Mahogany (*Entandrophragma cylindricum*): Radial longitudinal section (× c. 100): *c*, crystal in ray cell; *f*, fibre; *g*, gum deposits, in vessel and ray cells; *mc*, marginal cell of ray; *p*, paratracheal parenchyma; *r*, ray; *rc*, ray cell; *s*, septum across fibre; *sp*, simple pits of ray cells, seen in section; *v*, vessel; *vs*, end of vessel segment, showing simple perforation. *B*, Birch (*Betula alba*): Small piece of vessel from radial longitudinal section, showing scalariform perforation (× c. 320); the bordered pits on the vessel wall have been omitted.

contain a number of small gratings along its course; these are known as scalariform perforations (text-fig. 1*B*), and are often of value in recognising woods. Such perforations are seen in Birch (*Betula*) and Alder (*Alnus*): they furnish a useful means of differentiating between boxwoods and their substitutes, since they occur in true boxwoods but in only one of the substitutes. The walls of the vessels are perforated by bordered pits, which are generally very small and numerous; spiral thickening may also occur on the vessel walls. The chief function of the vessel is that of transporting water from the roots to the leaves. When present, tracheids also assist in this work. In conifers the work of water

conducting falls entirely upon the tracheids, which also constitute the supporting tissue of the plant. In hardwood the vessels also serve to some extent as supporting elements, but the function of support is, in the main, relegated to the fibres. Fibres (text-fig. 1*A*, *f*) are like tracheids in shape, but usually narrow. They may have thick walls; they often have slit-like pits, few in number, or there may be modified bordered pits. In hardwoods it is possible to trace all stages of gradation between tracheids and fibres. Fibres usually form the bulk of the wood, and it is to these that a wood owes its strength. These various elements may occur scattered in the wood without any special arrangement. Often, however, vessels are surrounded by parenchyma (perivasal or paratracheal parenchyma) (*p*): parenchyma may stretch in bands from ray to ray (concentric or metatracheal parenchyma), a feature well shown in the Soapwoods (*Sapotaceæ*). Fibres and parenchyma may alternate in tangential masses as in the Silky Oaks (*Grevillea*).

In some hardwoods the rays, like those of softwoods, are one cell wide (text-fig. 3*C*, *r*); usually their width exceeds a single cell, and then the ray has a more or less fusiform shape when viewed in a tangential direction. Very large rays occur in the Oaks (*Quercus*), and are called compound rays because some botanists hold that they are formed by the fusion of a number of small rays. Rays in hardwoods never contain tracheids, but in a number of tropical woods canals similar in appearance to the resin canals of certain conifers are found in them.

In temperate climates a new layer of wood is added annually to the periphery of the existing wood. Growth of the wood begins in the spring, and the first-formed wood is consequently known as spring wood. Wood formed later in the year is termed summer or autumn wood; the latter term is less satisfactory, as it implies that no wood is formed in the summer, whereas the formation of wood is a continuous process from the time it begins early in the year until it stops at the approach of winter. From a variety of causes—sometimes the formation of a band of fibres or parenchyma at the end of the season's growth, sometimes thickening of the cells or the deposition of tannins and other substances therein—the end of the summer wood is delimited, more or less clearly, from the spring wood of the following season, and the familiar annual rings are thus produced. The number of rings appearing on the end of a log does not necessarily indicate the age of a tree: some check in the normal growth of the tree, such as defoliation by caterpillars, may result in the formation of a ring in the middle of a season's growth. All that can be deduced from counting the rings is that a tree is not more than a certain age. In many woods it is impossible to distinguish between the spring and summer wood. The tracheids of the summer wood of conifers often have thicker walls than those of the spring wood (text-fig. 2*C*), and this increase in thickness may occur either gradually or sharply. A number of hardwoods, notably oak and ash, have large and very numerous spring vessels, while the bulk of the summer wood consists of fibres, the summer vessels being small and often not very numerous; such woods are called " ring porous," in contrast with " diffuse porous " woods like beech and lime, in which the vessels are evenly distributed and of much the same size throughout the year's growth. In the tropics timber may or may not show seasonal rings; this would appear to depend to some extent on the uniformity or otherwise of the climatic conditions, but the matter is not fully understood.

Conduction of water goes on in the more peripheral wood of the trunk. The more central tissue has a supporting function only, and often tannins, gums and other materials accumulate here; as a result the wood may become a darker colour and is referred to as heartwood, in contrast to the outer sapwood. In some trees the wood does not change in colour. Such trees are termed sapwood trees; although there is no visible difference, the inner wood has ceased to function as a water-conducting tissue and is, physiologically, heartwood.

In the heartwood of some trees the thin membranes covering the pits in the vessel wall are forced out like minute bladders into the cavity of the vessel. These tyloses (text-fig. 3*D*, *E*) stop up the vessel and in transverse section appear as a series of irregular lines running across the lumen. Their importance will be discussed later.

The choice of a wood for a particular purpose depends on its properties as compared with other materials like metals and stone, and upon its price, the price being intimately connected with the amount available and the demand for it. Wood has an advantage over many materials in being easy to work, and is strong relative to its weight; it is a good shock absorber, resistant to water and acids, and affected but little by changes in temperature. It has, however, certain undesirable properties; it is inflammable, it decays, its volume is affected by changes in humidity, and its strength is variable; further, it is available only in certain sizes, and large pieces may be difficult to obtain. Where the properties of a timber make it useful for some purpose the choice of a suitable wood is of importance. The number of woody plants is very large. The properties of their woods vary enormously: physical and chemical properties alone do not dictate the use of a particular species, the question of price and supply must also be considered. There are tropical timbers which appear to be eminently suited for certain purposes, but their appearance on the markets is so erratic, and the amount available so uncertain, that it is better to make use of better-known woods of which there are abundant supplies.

The use of a wood for ornamental purposes is least likely to be affected by the price and supply. In fact, the less common a beautiful wood, the more readily is it sought for by those with means: beautiful woods are always in demand for cabinet work, furniture and interior finish. The chief properties demanded of such a timber are that it shall be reasonably hard, that it shall not warp and that it shall finish with a smooth surface and take a high polish. Most woods which are admired for their beauty possess some feature which relieves the uniformity of their colour or texture; a pattern is thus produced to which the term figure is applied. Figure is an indefinite term, and may be produced in a variety of ways. In many timbers, such as many oaks, and in the silky oaks, the rays are very large and contrast in colour with the rest of the wood. If these woods be converted in such a way that the rays show their greatest area on the faces of the boards, such boards will show, to the greatest extent, the characteristic silver grain. The greatest area of ray will be obtained on boards which represent radial sections of the log, or, as they are termed in the trade, quarter sawn. The minimum of figure will appear on planks in which the faces are tangential sections; such pieces are termed plain sawn. In *Casuarina* the rays may be very large, appearing as dark-coloured patches which mar the beauty of the wood. A very large figure may similarly be produced in the silky oaks, and spoils an otherwise desirable wood.

Not all woods having large rays have a beautiful figure. Hornbeam (*Carpinus*) possesses aggregations of rays which may show a considerable expanse of ray tissue on quarter-sawn timber. The rays, however, are uniform in colour with the rest of the wood; they are easily seen if the wood is examined closely, but for all practical purposes the wood has no figure.

A timber may have small rays, relative to those of oak, and still show a very pleasing figure on the radial surface. Thus in Beech (*Fagus sylvatica*) the rays are numerous, and in Plane (*Platanus*) they are very abundant, and quarter-sawn boards of these timbers are very ornamental. In the Antarctic Beech (*Nothofagus*), trees closely allied to the beeches of north temperate regions, the rays are small, and the wood shows practically no figure on its radial face; a lens, however, reveals the characteristic beech-like figure in miniature. In most woods the rays are too small to produce any appreciable figure on quarter-sawn boards.

The tangential section of a wood is not necessarily devoid of figure: sometimes it shows a very bold figure, due to sharp differences in texture and colour of the spring and summer wood.[1] Figure produced in this way does not show on the radial face, appearing there as a series of vertical, parallel lines. This figure takes the form of a series of irregular U's or V's on the tangential surface, one within the other. Pitch Pine (*Pinus palustris*), so frequently used for church furniture, will be a familiar example of this type of figure, and it is well shown in Douglas Fir (*Pseudotsuga Douglasii*), which, usually in the form of plywood, is sometimes used for panelling.

The rays may contribute to the figure on the tangential face. In a number of tropical woods the rays are arranged in tiers or parallel rows (text-fig. 3*C*). They are visible on the tangential section as rows of fine dots, arranged roughly in parallel lines; they are known as ripple marks. Ripple marks give a peculiar and beautiful sheen to the wood when viewed from certain angles, and the wood appears to have a texture not unlike that of a piece of fabric. Ripple marks are probably seen at their best in the Burmese Mahogany or Thitka (*Pentace burmanica*), and they are also found in the true Mahoganies (*Swietenia*).

Woods in which there is abundant parenchyma often show a beautiful figure due to the contrast between the fibres and soft tissue. In Elm (*Ulmus*) the vessels of the summer wood are in undulating tangential lines associated with parenchyma, and in the plain-sawn timber appear in the form of zigzag lines, producing the characteristic partridge-wing figure. In Indian Laurel wood (*Terminalia tomentosa*) there is a great deal of parenchyma surrounding the vessels, and it is this to which the figure of the wood is chiefly due; unfortunately it is only visible when the light strikes it at certain angles, and a well-figured panel may appear quite plain in certain lights.

In some woods the fibres not uncommonly lie obliquely instead of in the vertical plane; in these, adjacent masses of fibres may slope in opposite directions. This characteristic detracts from the working qualities of the wood in rendering it cross-grained, but it often produces a highly ornamental effect. On the radial face adjacent parallel bands appear to have a different texture, so that the wood has a striped appearance, termed ribbon figure. The effect is produced by adjacent blocks of fibres reflecting the light differently owing to their having been cut at different angles. Ribbon figure is often seen in the African Mahoganies (*Khaya*), and in woods of the Dipterocarpaceæ. Sometimes the fibres take a wavy course, producing what is known as wavy grain. This again makes the wood difficult to work, but produces, owing to the differently cut surfaces of the fibres reflecting the light differently, a very fine figure in the form of a series of transverse ripples or waves, sometimes termed ripple figure. No wood shows this feature better than the Australian Blackwood (*Acacia melanoxylon*), a wood which, at its best, probably gives as beautiful a figure as any wood.

Figure may be caused by differences in colour in different parts of the wood. In Olive (*Oleo europæa*) the zones of colour vary from light yellow to dark brown. In the Marble woods and Zebra woods, produced by species of Ebony (*Diospyros*), alternating zones of black or dark brown, and white occur, and produce a very striking effect. The cause of the differences in colour is not understood.

Irregularities in growth produce some of the most striking and beautiful figures. Under this head is included the marking of growing timber by animals such as rodents and deer, and its subsequent healing: the irregular growth of small branches, with the formation of burrs, tightness of the bark, and so on. Such well-known figures as bird's-eye maple and burr walnut are due to one or other of these causes. The pith flecks seen in birch, certain maples and other woods are due to the attacks of boring grubs, whose galleries become filled

[1] In the timber trade it is usual to refer to this type of figure as "grain."

subsequently with parenchymatous tissue. A great deal remains to be discovered in regard to these irregular types of figure: in any case a fuller consideration does not come within the scope of this paper.

Figure may be detrimental to the use of a wood for certain purposes. Douglas Fir yields an excellent timber for flooring, but if plain-sawn timber is used, hard wear results in the more rapid wearing away of the softer spring wood, and if the floor-boards have been laid incorrectly, as they frequently are, flakes of summer wood break away, or as it is usually termed, shell out. Deal (Pine) tables which are frequently scrubbed suffer in the same way. Plain-sawn boards used for either purpose should be laid with the face which comes from nearest the centre of the tree downwards. Preferably boards in which the annual rings run obliquely through the wood should be used. In such timber it will be seen that the faces of the planks are neither radial nor true tangential surfaces. The marked contrast between spring and summer wood in Douglas fir renders it unsuitable for painting; with increase of humidity the summer wood, with its thick-walled tracheids, absorbs more water than the spring wood and consequently swells more. This lifting of the grain will show up under several coats of paint and produce an unsightly surface.

A large number of woods have practically no figure; their rays are small, there is no marked difference between spring and summer wood, and no localisation of parenchyma, fibres or vessels. Such woods, having a more or less even structure throughout, are of great value for a variety of purposes; they will cut evenly in any direction, without chipping or tearing, and in general are not likely to warp much. Lime (*Tilia*) has such an even structure, and is in consequence a valuable wood for carving. It is also used for cutting-boards, since its uniform structure does not bias the knife in any direction. Grew notes the same features in Sallow (*Salix*), and remarks: ". . . some Woods are soft, as Deal, and Sallow. . . . Sallow, from the great number of Aer-Vessels spread all over it . . . being well wrought upon, which way soever you cut it: . . . Again, in Sallow, by the equal spreading of the Aer-Vessels, the Softness is equal or alike in all Parts. . . . Shoomakers also make use of it for their Carving-boards. Because being every where equally soft, it turns not the edge of their Knives. . . ." Of Lime he writes: "Again, some Woods are soft, but not fast; others are both, as Linn [Lime]: its Softness, depending on the numerousness and equal spreading of the Aer-Vessels: its Fastness, on the closeness of the true Wood, and the shortness, and smallness of the Insertions [rays]. For which cause, it is of excellent use for many purposes; and particularly, for small Sculpture: . . ." The same properties make lime useful for the cores of piano keys: for such a purpose, any wood which warped or did not cut cleanly would clearly be useless.

Other timbers used for carving on account of their even structure are Pear (*Pyrus communis*) and the Indian wood known as Haldu (*Adina cordifolia*). The former has an additional advantage for this purpose in that its colour approaches that of the human skin. Pear was commonly used for wood-cuts, and nowadays is also used for mathematical instruments and for wood-screws: for all these purposes a wood is required which finishes with a smooth surface and retains its shape.

Uniformity of structure also characterises a number of coniferous woods, and these are used for special purposes: particularly worthy of note are the Kauri Pine (*Agathis*), Pencil Cedar (*Juniperus* spp.) and Weymouth Pine (*Pinus strobus*). The first is used, among other things, for the linings of fermenting vats in breweries; doubtless other timbers would stand the strain as well as *Agathis*, but since the vats have to receive a very thorough cleansing after each brew, it is essential that the wood used be of an even texture, so that all parts wear away at the same rate. A wood having a marked difference between its spring and summer wood would rapidly wear into furrows and ridges, affording

in this condition a haven for bacteria and other micro-organisms, and making the work of cleansing unnecessarily troublesome.

The Pencil Cedars (especially *Juniperus virginiana*) are used largely for pencil making. For this purpose a wood is needed which will cut evenly and easily obliquely to the grain; it must be soft enough to cut with a blunt penknife, for few people possess sharp ones, and it must possess an even texture in order that it may be grooved accurately to take the lead and finish with a smooth surface so that it is comfortable in the hand, whether painted or not. Further, owing to the avidity with which many people chew the ends of their pencils, it is desirable that the wood have a pleasant, or at least not an unpleasant taste. Few timbers meet all these requirements. It would appear that the wood of *Juniperus* (text-fig. 2*B*, *D*) has been found to be the only really satisfactory timber for the purpose: the pleasant odour which the freshly cut wood possesses is an additional point in its favour.

Weymouth pine has many uses; for the making of pattern blocks the wood is prized, since, owing to its uniform structure, it cuts evenly in any direction and finishes smoothly; craftsmen, in fact, say that it "cuts like cheese." The timber is also used for ships' decks, its value in this position being that it always presents a smooth surface despite the traffic upon it and the frequent and thorough scouring which it receives.

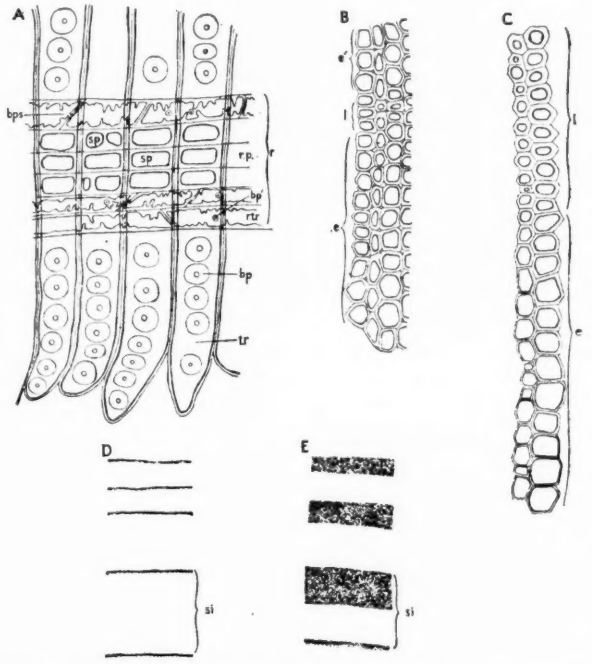
It is reasonable to suppose that uniformity of structure accounts for the excellent resonating properties possessed by certain timbers. No wood is found to equal Spruce (*Picea*) in this respect, and it is for this reason that it is used for sounding-boards of pianos, the bellies of violins, and for parts of other musical instruments where resonance is required.

An even structure associated with hardness is found in the Maples and Sycamore (*Acer* spp.), and such timbers can be relied upon to wear both evenly and well. This accounts for the use of maple rollers for machinery, and the same wood makes one of the best block floors. When roller skating was popular, advertisements of rinks often referred to the "rock maple floors." Rock Maple is the timber of *Acer saccharum* and makes excellent floors. That the woods wear evenly makes them very desirable for the manufacture of dairy and kitchen furniture and utensils; no amount of scrubbing alters the smoothness of their surface, and in consequence they hold little dirt. In mediæval times maple was used for drinking vessels, a fact recorded in an old wassail song:

"Our bowl is made of the green maple tree."

For turnery work a wood must be reasonably hard and also even textured, for it must cut readily in any direction. Many woods are suitable for this purpose: Beech (*Fagus*) is much used, and a good deal of oak furniture with turned legs and rails has these parts made of beech, since it turns much more readily than the less even textured oak. Like maple, beech is sometimes used for rollers, but is not so satisfactory for the purpose, as it will not stand the alternate wetting and drying to which many rollers are subjected. Elder (*Sambucus*), Dogwood (*Cornus*) and Holly (*Ilex*) are other useful turnery woods, and Box (*Buxus*) is, of course, much used. In box the structure is uniform: the vessels are very small and the walls of the fibres and parenchyma are very thick; thus the wood is hard and dense, with an almost flinty texture. It is well suited for making scales and other mathematical instruments. But its greatest value is for the making of engraving blocks; it is able to withstand the hard usage without wearing, and consequently producing a blurred reproduction; it can also be cut with precision, and does not warp. According to Howard, the best box is used for engraving blocks for cheap catalogues. It would seem that it is more economical to buy the best wood for the purpose, as with it a good illustration is produced on a cheap paper; inferior quality box demands a good paper for reproduction. Even the sawdust of boxwood has a special use; it is hard enough to form a mild abrasive, and is used for polishing jewellery.

Although they have a uniform structure and are capable of taking a good finish, the woods of the Willows (*Salix*) and Poplars (*Populus*) tend to wear to a woolly surface. This texture, associated with softness, makes the woods of special value for some purposes, especially where they are required to withstand the impact of heavy bodies. When a soft wood receives an impact it yields, but many woods, like those under consideration, are sufficiently resilient to recover their original form when the stress is removed: a hard timber would not yield, and as a consequence would tend to chip and splinter. In factories where heavy castings and such-like commodities are being shifted, poplar makes an excellent flooring owing to its soft and somewhat resilient nature. Added to this, poplar is one of the woods most resistant to fire, an additional point in its favour when used for constructional work in factories.



TEXT-FIG. 2.—*A*, Scots Pine (*Pinus sylvestris*): Radial longitudinal section (× c. 100): *bp*, bordered pit of tracheid; *bp'*, bordered pit of ray tracheid; *bps*, bordered pit of ray tracheid in section; *r*, ray; *rp*, parenchyma cells of ray; *r.tr*, ray tracheid; *sp*, simple pits of ray parenchyma; *tr*, tracheid.

B, East African Pencil Cedar (*Juniperus procera*): Transverse section (× c. 90); note even structure due to small proportion of thick-walled tracheids (the figure shows only about half the number of thin-walled tracheids of the season's increment in each row); *e*, thin-walled tracheids; *e'*, thin-walled tracheids of the following season; *l*, thick-walled tracheids.

C, Douglas Fir (*Pseudotsuga Douglasii*): Transverse section (× c. 90); note uneven texture due to large proportion of thick-walled tracheids; lettering as *B* (only about half the number of thin- and thick-walled tracheids of the season's increment in each row).

D, East African Pencil Cedar: Diagram of end grain (× c. 10), showing proportion of thick-walled elements in season's increment; *si*, season's increment; area of thin-walled tracheids white, area of thick-walled tracheids dotted.

E, Douglas Fir: Diagram of end grain (× c. 10), showing proportion of thick-walled elements in season's increment; *si*, season's increment; area of thin-walled tracheids (spring wood) white, area of thick-walled tracheids (summer wood) dotted.

In structure willow is almost identical to poplar. It is used for the linings of carts and barrows, especially for the bottom boards. Its value in this position is that it does not split or chip under the impact of heavy bodies. If, for example, a vehicle is being used for carting stones, these, as they are thrown into the cart, abrade the bottom, but merely cause it to become woolly instead of chipping: the woolly surface, like a layer of felt, furnishes additional protection to the boards. The sides of such a vehicle, however, have to withstand friction rather than impact, and for this a tough wood like Common Elm (*Ulmus campestris*) is more suitable. Willow is also used for brake-blocks: its woolly texture fits it for such a purpose, for there is less tendency for it to wear smooth and thus there is always a good surface for gripping the wheels; a hard wood would rapidly wear to a smooth surface and its utility, in consequence, be impaired. Like poplar, willow is fire-resistant, and this is an additional advantage, for the heat engendered by friction against the wheels has little effect upon it.

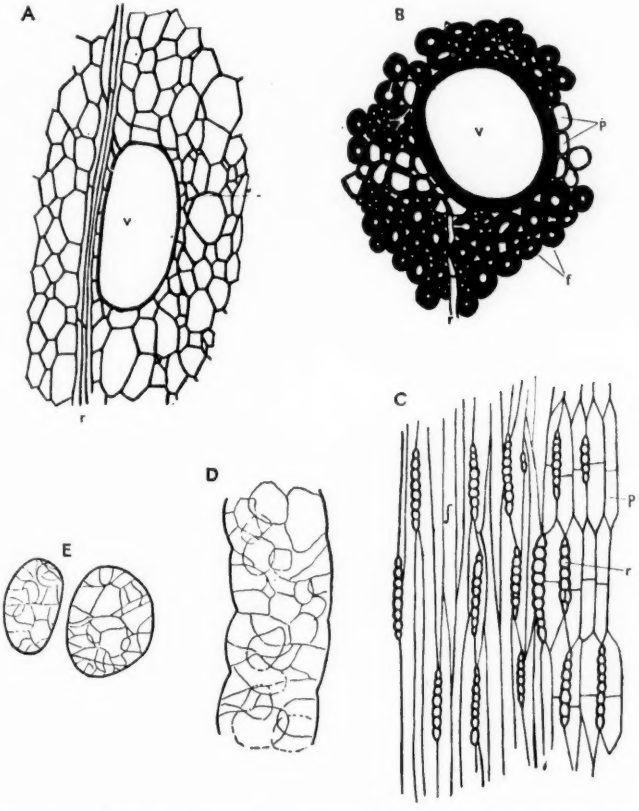
Where the vessels are of a uniform size and evenly distributed the wood possesses a number of minute air pockets regularly scattered. If the walls of the cells and vessels be reasonably thin and the wood fairly soft, it may be assumed that the wood will be more or less resilient. Willow has this structure and furnishes an excellent material for the manufacture of cricket bats. A hard non-resilient wood would quickly splinter on impact with the ball, and the effect on the batsman's hands need not be described. It is not possible to identify the different species of willow under the microscope, but only the Cricket Bat Willow (*Salix cærulea*) is used for making the best bats. Why this is so, or why, for that matter, poplar should not prove equally suitable, is not fully understood. For the same reason willow is of value for the construction of artificial limbs, and the wood of the Ohio Buckeye (*Æsculus glabra*) is used for the same purpose. The structure of the latter wood is not very different from that of willow.

Resilience makes a wood valuable for many purposes: sleepers, in this country at least, are largely made from the wood of the Scots Pine (*Pinus sylvestris*). When a train passes over a sleeper, the chairs carrying the rails are pressed into it, and the sleeper in turn is ground into the ballast of the track; when the load is removed, the sleeper, thanks to the resilience of the wood, resumes its normal shape. Certain species of Eucalyptus have been tried for the same purpose, but have proved less satisfactory, since the wood does not give to the load, and the chairs, when pressed on to the sleeper, tend to break the resistant fibres of the wood. The fibres fail, not through softness, but because they are too hard to give under the stress. Other species of Eucalyptus, such as Jarrah (*E. marginata*), furnish useful sleeper wood, but there is little doubt that in this country Scots pine is the favourite wood for this purpose, and probably more satisfactory than the harder and extremely durable jarrah. There has been much discussion, also, concerning the relative merits of Scots pine and jarrah for wood paving-blocks. Both timbers have many points in their favour, those of the pine depending largely on resilience and the ability of the wood to take up a preservative, while those of jarrah depend to a great extent on its hardness and durability. The softer wood gives, as would be expected, a much less noisy surface, for it yields to traffic, and is, in fact springy; it also wears more evenly, whereas jarrah, by chipping and splintering, is more apt to wear unevenly.

Where the vessels are numerous and the walls of all the elements are thin, the wood has a light, porous nature. Such a wood is the Horse Chestnut (*Æsculus Hippocastanum*); it has, naturally, little substance, since the greater part of the wood is occupied by air. It is of little value, and this probably explains its use for cheap toys and the backs of cheap brushes; for veneering the backs of scrubbing-brushes, however, the wood is favoured because of its clean, white appearance. The wood is also used for shelves on which fruit is

stored, the porous wood tending to absorb moisture and thus to keep the fruit reasonably dry; the chance of fungal infection is thus reduced.

Cigar-box Cedar (*Cedrela* spp., especially *C. odorata*) also has an open, porous structure, although less regular than that of horse chestnut. This wood is used for the manufacture of cigar-boxes; owing to its porosity it allows any excess moisture from the fresh cigars to pass out of the box readily, but prevents them from becoming too dry by permitting the passage of atmospheric moisture into the box. In some cases, however, as Howard points out, every effort is made to prevent the wood from serving this purpose by plastering the box with paper labels. Other properties of the wood make it valuable for cigar-boxes. Its odour is said to enhance the smell of the cigars, and at the same time to be obnoxious to certain insects which damage the tobacco.



TEXT-FIG. 3.—*A* and *B*, transverse sections of a light and a heavy wood to show difference in size of elements and thickness of their walls; scale of *A* is approximately $\frac{1}{3}$th that of *B*. *A*, Balsa wood (*Ochroma sp.*) (× c. 70); weight 7½-12 lb. per cub. ft. *B*, Lignum vitæ (*Guaiacum sp.*) (× c. 340); weight 72-83 lb. per cub. ft. *C*, Andaman Padauk (*Pterocarpus dalbergioides*): Tangential longitudinal section, showing storeyed rays and parenchyma (× c. 70). *D* and *E*, False Acacia (*Robinia pseudacacia*): Tyloses in spring vessels. *D*, vessel in longitudinal section. *E*, vessels in transverse section (× c. 55). *f*, fibres; *p*, parenchyma; *r*, rays; *v*, vessels.

An open porous structure is exceptionally well shown in the Balsa wood (*Ochroma* spp.). All the elements have very thin walls (text-fig. 3*A*), and the transverse section, seen under the microscope, has the appearance of a piece of lace. The greater part of a block of this wood, of course, consists of air, and the wood is consequently extremely light, weighing from $7\frac{1}{2}$ to 12 lb. a cubic foot, or having a specific gravity of about 0.16. Owing to the large amount of air it contains, the wood is an extremely poor conductor of heat, and for this reason is used for a refrigerator packing. For similar reasons the wood of the Pith tree (*Æschynomene aspera*) is used for making the so-called pith helmets.

In contrast with these very light woods, heavy timbers like Lignum-vitæ (*Guaiacum* spp.) and Ekki (*Lophira procera*) have small vessels and all the elements are thick-walled; in other words, the bulk of the wood consists of wood substance (text-fig. 3*B*) and not air spaces. The wood substance itself weighs approximately the same in all timbers, varying round about a specific gravity of 1.5; a light wood floats because it contains much air. When the lumina of the elements become filled with water, as in water-logged timber, any wood sinks, because it is heavier than an equivalent mass of water.

A number of timbers have the property of breaking cleanly without forming long splinters; while this feature depends largely on the mechanical properties of the fibres, it is possible, in some cases at least, to suggest contributory causes from a knowledge of the anatomy of the wood. An example is furnished by the Padauks (*Pterocarpus*). Wood from trees of this genus is used in the United States for the panelling of Pullman cars. Apart from its ornamental appearance, it is said not to splinter when broken so that in the event of a smash, the chance of injury from jagged pieces of wood is minimised. Microscopic examination of the longitudinal tangential section of the wood reveals a possible explanation; the rays are arranged in parallel rows (storeyed) and the parenchyma has a similar arrangement (text-fig. 3*C*); this would appear to give a series of transverse bands of weakness, and may account for the clean fractures of the wood. One of the most remarkable instances of clean fracture is in the West African Obeche (*Triplochiton scleroxylon*). If a small piece of this wood be broken across, a certain amount of splintering will occur on the tension side, but beyond this the fracture is often so clean that it is possible to make out the structure of the transverse surface without first cleaning it with a knife. In this wood the abundant parenchyma has a more or less storeyed arrangement, and the lines of junction between the cells no doubt furnish lines of weakness along which the wood breaks. This wood is relatively new to commerce, and is being used, I understand, for motor-body work, but whether for its clean fracture or for other desirable properties, I do not know. The wood is also sometimes used for making blackboards, and certainly its even structure fits it for this purpose, although it would appear to be rather soft for such articles.

The presence of tyloses in the vessels may be a deciding factor for the use of woods for special purposes. For tight cooperage a wood is required which is tough and strong, capable of withstanding alternate wetting and drying, and of a non-porous nature; further, in most cases it must not affect the taste, odour or colour of the liquid which the barrel will ultimately contain. Few woods meet all these requirements. Many of the oaks are satisfactory, except for their porous nature; in some oaks it is possible to blow bubbles through a long stick of the wood. The American White Oaks (*Quercus alba*, etc.) are not usually porous, because generally their vessels are filled with tyloses, and are thus effectively sealed. Such timbers are used for tight cooperage. When alcoholic liquids are casked up, allowance must be made for fermentation; some sort of safety valve is necessary to permit the escape of carbon dioxide. This is accomplished by inserting into the barrel a little plug of a porous wood; such a plug is termed a spile peg, and is made from the wood of a red oak (*Quercus rubra*, etc.). The

red oaks normally have no tyloses in their vessels. The wood is bought in the form of billets, known in the trade as free-blowers, and they are tested for their suitability for spile pegs by blowing through them into a bucket of water; those through which bubbles cannot be blown are rejected.

Probably no wood shows the development of tyloses to such an extent as the False Acacia (*Robinia Pseudacacia*) (text-fig. 3*D*, *E*). This is a hard, heavy wood, and, according to some authorities, is even more durable than oak or chestnut when used for fencing-posts. It seems possible to account for this property by the presence of the abundant tyloses, which, by plugging up the vessels, at least block up some of the cavities which would afford a resting-place for fungus spores.

The presence of gums and other deposits in the lumina of the elements may affect the value of a timber. Joiners find that their tools require frequent sharpening when used on Teak (*Tectona grandis*), in which white deposits of apatite frequently occur in the vessels. In the Cigar-box Cedar (*Cedrela odorata*), a hard, bright red gum is found in the vessels: in some species of *Cedrela* there is a soft gum in the vessels, and as this may ooze out of the wood, the timber is useless for the manufacture of cigar-boxes. Other timbers possess soft gums, and as a consequence their value is diminished. The beautiful West African Iya (*Paradaniella Oliveri*) is rendered unsuitable for furniture for this reason, efforts to get rid of the gum having so far proved useless. Similarly the equally beautiful Australian Rose Mahogany (*Dysoxylum Fraseranum*) must be selected with great care, because it contains a gum which is liable to bleed; apart from this it appears to be a good timber for cabinet work.

The presence of an oily material in the wood may make the timber useful for special purposes: teak, for example, is used for backing the armour-plate on battleships largely because metal in contact with it is not corroded; the wood has an additional advantage in this position in that it breaks with a clean fracture, so that in the event of its being broken by exploding shells, there is less liability of injury from jagged pieces of wood. In lignum-vitæ there is an oily substance, a gum resin, which to some extent is responsible for the usefulness of the wood. This wood is extremely hard, and the gum resin makes the wood practically self-lubricating. Probably the most important use to which the wood is put is the packing (bushing) of propeller-shafts in steamships. In such a position it is necessary to use a self-lubricating material, as it cannot be reached for oiling. Howard records that the wood, even in this position, lasts for as long as three years on such a ship as the *Mauretania*, truly a remarkable tribute to the wood. The wood is also used for the sheaves of pulley-blocks, where the value of its self-lubricating properties will be apparent. It is perhaps not surprising that so hard a wood can be sawn with the greatest of ease, because it lubricates the saw during the process. The presence of the waxy substance makes the wood an excellent fuel, and a certain amount is used in the United States for this purpose. As fuel, however, its price puts it beyond the reach of all but the wealthy.

Examination of a timber under the microscope does not always enable one to account for its properties, however carefully the wood may be studied. It has already been pointed out that one wood alone is suitable for the manufacture of cricket bats, although in structure it is identical with a number of other woods. It does not tell us why woods like teak and jarrah are fire-resistant, why the Lancewood (*Oxandra lanceolata*) is so flexible and elastic or why Greenheart (*Nectandra Rodiaei*) resists the attacks of the shipworm so well. The study of timber structure is only one aspect of the subject, and must proceed hand in hand with investigations on the physical and chemical properties of the wood before we can hope to obtain such information of the properties of any timber as will enable us to predict the uses for which it is likely to be most suitable.

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THURSTON WING-TIP ROTORS

CONTROL BEYOND THE STALL

BY

A. P. THURSTON, D.SC., F.R.AE.S., M.I.AE.E.

Three great drawbacks of modern aeroplanes, from a safety point of view, are their tendency to stall, their high landing speed, and their low gliding angle.

The use of wing-tip slots for preventing lateral instability is well known, but they do not materially reduce the landing speed. Moreover, they cannot be used along the whole span without making the wing unstable. The best length of wing-tip slot for securing stability and maintaining the lift coefficient is about 40 per cent. of the semi-span.

FIG. 1.

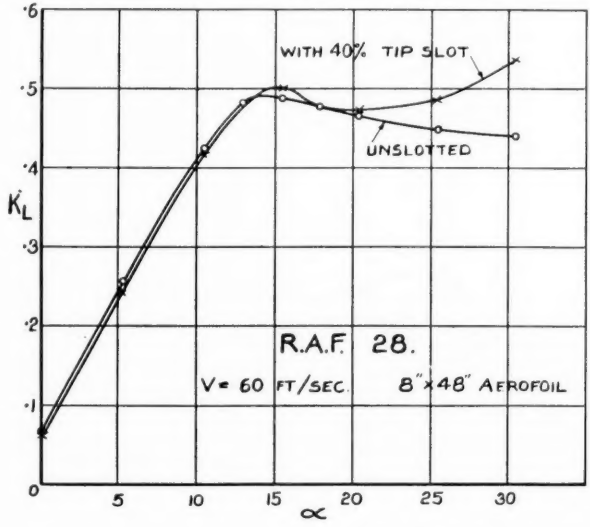


Fig. 1 shows the lift curve of R.A.F. 28 with and without optimum wing-tip slots of 40 per cent. semi-span taken from R.A.E. tests which were made during an investigation of the effects of wing-tip slots on spinning. The slot increases the maximum lift coefficient by 2 per cent. It secures lateral stability by keeping the lift coefficient approximately constant up to about 25°.

It is generally accepted that the tendency to stall is caused by the air breaking away from the back of the wing when the opposing pressure gradient in the boundary layer on the back of the wing reaches a critical amount. This breaking away causes a drop in the lift curve which invariably takes place on one side of a machine before the other, thus unbalancing the rolling moments and resulting in a spin. The slot delays this break away and thereby laterally stabilises the

wings and decreases liability of spinning. The flat gliding angles and high landing speeds of modern machines are due to clean design and low drag coupled with high wing loading. Increasing the gliding angle at once increases the speed which can only be dissipated by long and useless glides before landing.

The flat gliding angle, moreover, makes it difficult to land in an aerodrome with high surrounding obstacles, since, if the aerodrome is approached at a steep angle, the speed of the machine will increase at such a rate that it cannot be landed.

FIG. 2.

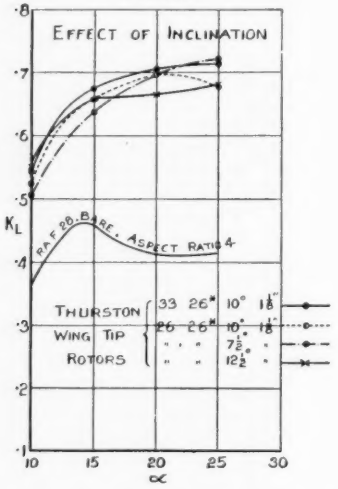
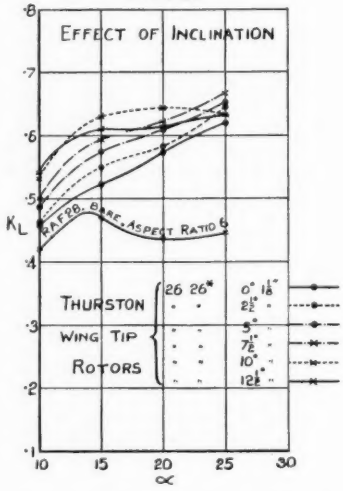


FIG. 3.



The slot has not been used to decrease the landing speed to any appreciable extent because it is not possible to land machines safely at angles in which the slots are giving their maximum lift. It is true that the slot does allow a machine to be flown more slowly and that it does increase the angle of descent at large angles of incidence; but these angles of incidence are so great as to make their use impracticable for structural and other reasons. What useful purpose, it may be asked, is served by flying slowly with slots if no extra ability to land slowly and safely is obtained?

The object of this article is to draw public attention to a new form of control which it appears will give a powerful stabilising effect over a wider angular range than with the wing-tip slot and which will at the same time enable a machine to be landed more slowly and at a steeper angle of descent. Other advantages of this new control will appear.

Fig. 3 shows a series of lift curves for R.A.F. 28 fitted with a pair of rotors 26, 26*. These rotors are not so good as the pair 26*, 33; nevertheless, at angles of 25° the rotors increase the lift coefficient by 49.5 per cent., at 20° by 48 per cent., at 15° by 32 per cent., and at 10° by 28.6 per cent.

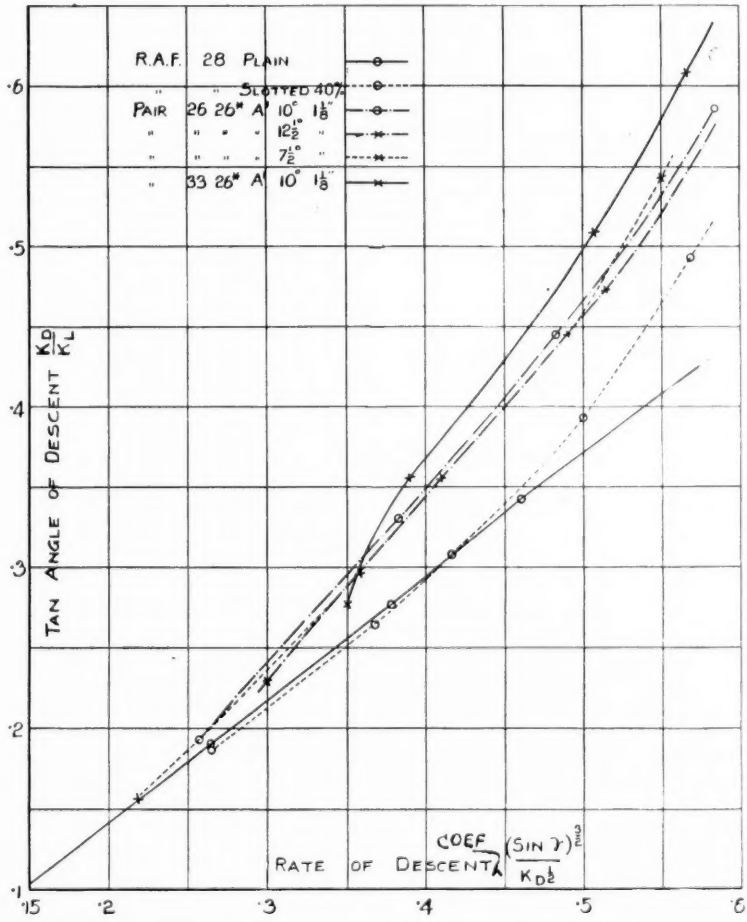
Referring to Fig. 1, it is seen that the corresponding slot decreases the lift coefficient below 14° and only increases the maximum lift coefficient by 2 per cent. for any angle below 27°.

In Fig. 2 the lift coefficients K_L for R.A.F. 28, fitted with a pair of Thurston Wing-Tip Rotors, Nos. 26* and 33, are shown at various inclinations with the chord of the main plane. The lift coefficient of the bare wing is shown plotted on the same figure. The rotors increase the lift coefficient at 25° by 75 per cent.,

at 20° by 71 per cent., at 15° by 48 per cent., and at 10° by 48.5 per cent. These figures refer to a special test where the rotor diameter was proportionally increased by decreasing the aspect ratio of the wing to 4.

Both Figs. 2 and 3 show the effect of varying the inclination of the axis of rotation of the rotor and indicate that a strong positive control can be obtained by altering at will, by any suitable means, the inclination of this axis.

FIG. 4.



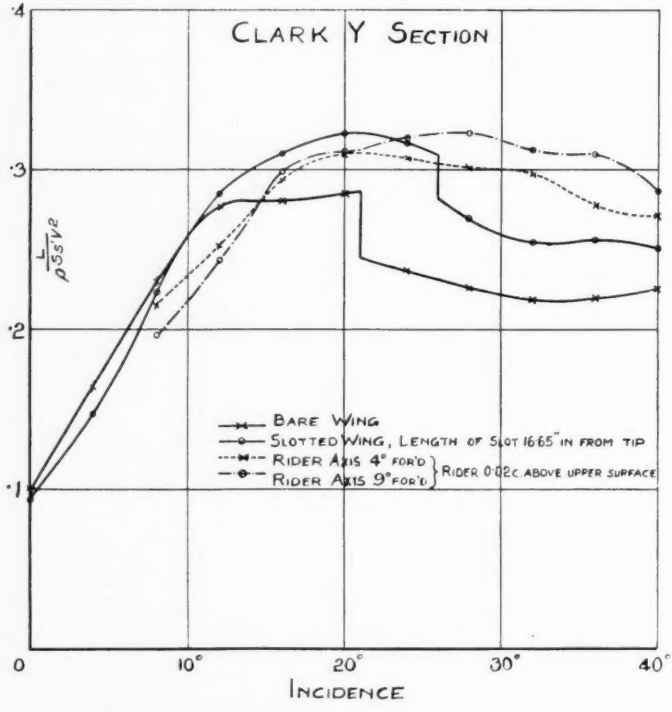
It will be noticed that the curves of the lift coefficients are in many cases rising at a steep angle at 25° inclination, indicating that considerably higher lift coefficients are obtainable at greater angles. This, in fact, has been found to be the case.

The criterion for safe landing is that the gliding angle shall be as steep as possible for a given rate of descent determined by the amount of energy which can be safely absorbed in the landing gear.

The gliding angle is given by $\tan \gamma = K_D/K_L$.
Rate of descent $= V \sin \gamma$.
Now $W = K_R \rho S V^2$ where ρ at 15°c. and 960 mm. = .002378.
$K_R = K_D/\sin \gamma$ $\therefore$ $V^2 = \text{const}/K_R = \text{const} \times \sin \gamma/K_D$.
$\therefore$ rate of descent $= (\sin \gamma)^{3/2}/K_D^{\frac{1}{2}}$.

In Fig. 4 K_D/K_L is plotted against the rate of descent for wing alone for R.A.F. 28 with and without optimum wing-tip slots and with various pairs of wing-tip rotors.

FIG. 5.



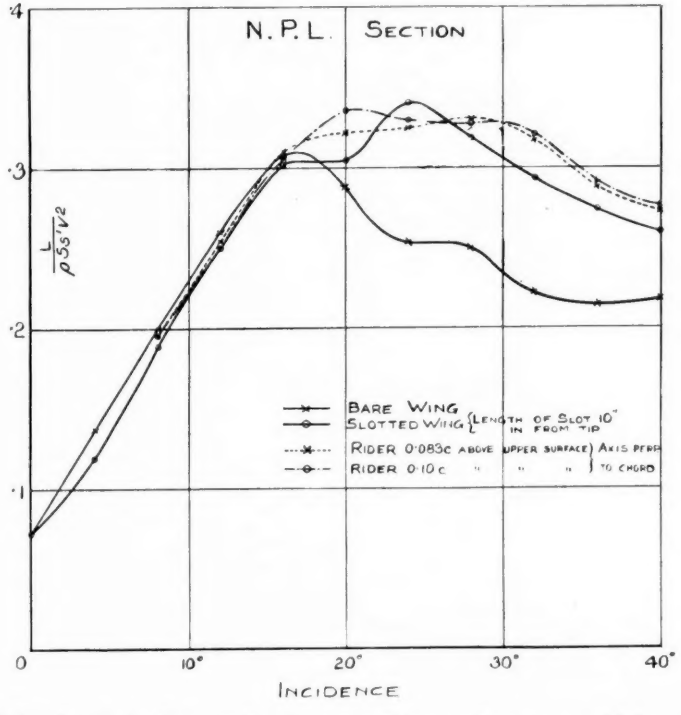
For rates of descent of 0.4 and less the angle of descent of the slotted wing with optimum slot is decreased and for rates of descent of 0.45 it is increased by 1.5 per cent., for rates of descent of 0.5 by 2.7 per cent., and of 0.55 by 13.4 per cent. Since a rate of descent coefficient of 0.5 is about the maximum which modern conditions permit, it follows that the optimum slot does not permit the gliding angle to be increased by more than 2.7 per cent. An examination of the rotored wing under the same conditions shows that at rates of descent of 0.4 the angle of descent is increased by 25.4 per cent., of 0.45 by 28.5 per cent., of 0.5 by 34 per cent., and of 0.55 by 41.5 per cent. In other words, whereas the slotted wing, under favourable conditions, increases the angle of descent by about 2.7 per cent., the rotored wing, under the same conditions, increases the angle of descent by 34 per cent.

If the gliding speed $= V$ then $W = K_R \rho S V^2$ where $K_R = K_L/\cos \gamma$.
$\therefore$ $V^2 = \text{constant} \times \cos \gamma/K_L$.
$\therefore$ gliding speed $= (\cos \gamma)^{\frac{1}{2}}/K_L^{\frac{1}{2}}$.

This gliding speed may be plotted against the tan of the angle of descent K_D/K_L when a series of curves, corresponding to those shown in Fig. 4, will be obtained.

It will be seen from Fig. 4 that for a rate of descent coefficient of 0.55 corresponding with an angle of attack of about $22\frac{1}{2}°$, the angle of descent of the rotored wing is about 30°. Hence, at this rate of descent the nose of the machine would be down about $7\frac{1}{2}°$ from the horizontal.

FIG. 6.



Obviously, in landing under these conditions advantage could be taken of the higher lift coefficient available, and of the energy stored in the machine and rotors, to land the machine at a speed much below the gliding speed.

The readings plotted in Figs. 2, 3 and 4 were made at the R.A.E.

The stabilising effect of the rotors may be shown by plotting the rolling moments against the inclination.

In Figs. 5 and 6 the rolling moment, with early forms of rotors, is given as coefficients in the form $L/\rho S s' V^2$, where

S = area of half wing.

s = span of half wing.

a = distance of centre of whole wing from axis about which measurements were taken.

$s' = s + 2a$.

The numbers given are then of the same order as half the lift coefficient.

The section used in Fig. 5 is approximately Clark Y. The span of the half wing was 25 inches, the chord 6 inches, and the length of slot 16.65 inches. The

rotor was of cambered metal strip 12 inches in diameter by $\frac{1}{2}$ inch wide and inclined forward 9°.

It will be seen from this figure that the slot delays the stall, but does not prevent it, whereas a smaller rotor completely cuts out the stall and gives a flat rolling moment up to angles of 40°.

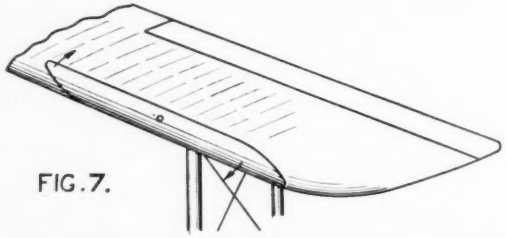


FIG. 7.

The section used in Fig. 6 is an N.P.L. one. The span of the half wing was 18 inches, the chord 6 inches, and the length of slot was 10 inches. The axis of the rotor was perpendicular to the chord.

Again it will be seen that the slot delays the stall, but does not prevent it, and that the rotor gives a much flatter curve than the slot and of the same maximum rolling moment.

The readings plotted in Figs 5 and 6 were made at the N.P.L.

A general idea of the construction and appearance of a machine fitted with wing-tip rotors may be obtained from Figs. 7, 8, 9 and 10.

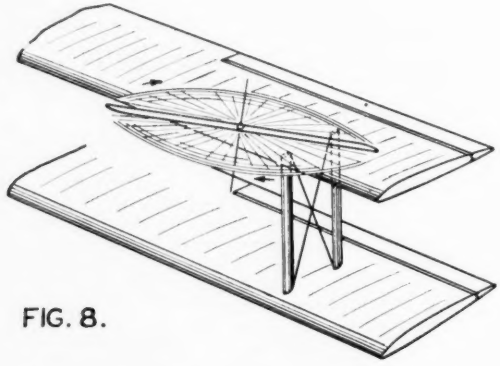


FIG. 8.

Fig. 7 shows a wing-tip rotor at rest on the front edge of a wing.

Fig. 8 shows the same rotor autorotating when the machine is stalled.

Fig. 9 is a side view of the rotor and main wing viewed slightly from below and shows that the rotor creates a living slot above the leading edge of the main plane.

Fig. 10 is a side view showing a cross section of the rotor and main plane.

There are many ways of carrying the rotor without resistance when not in action and many ways of bringing the rotor automatically into and out of action.

Summarising, it may be stated that, the experiments demonstrate that the rotored wing gives slow landing speeds and steep angles of approach, that Thurston wing-tip rotors give strong anti-stalling and lateral stabilising effects, and the variation of lift with inclination of the rotor axis suggests that the rotors

might be used for lateral control both above and below the stall. These experiments further demonstrate that two rotary wing devices, popularly known as windmill planes, or helicopters, may be fitted upon the main wing of an ordinary aeroplane for use in landing or taking off and that such windmill planes, or helicopters, will not upset the stability of the aeroplane, but in fact will stabilise it.

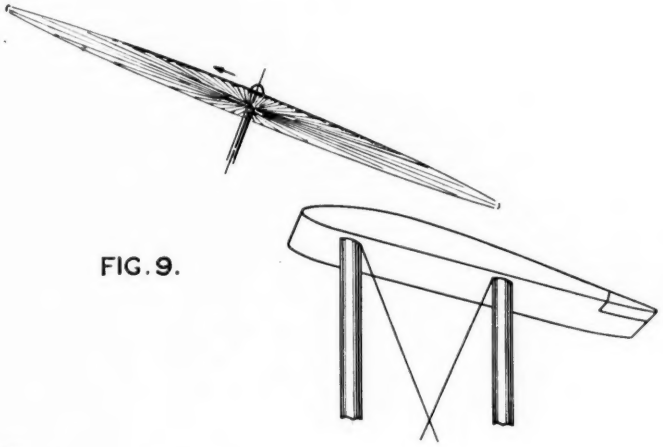


FIG. 9.

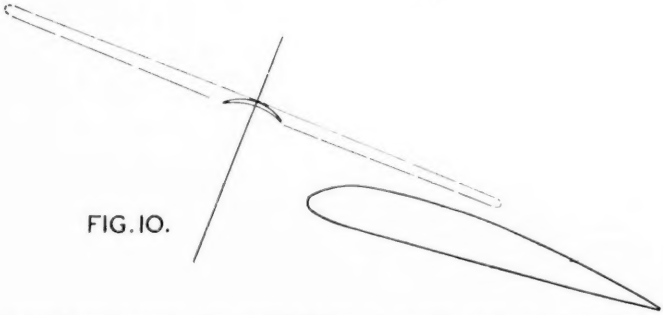


FIG. 10.

The experiments open the possibilities of a new type of aircraft combining the properties of both the fixed wing and the windmill, or helicopter, plane and indicate that there is still a wide field of development in aeronautics in relation to the association of fixed and moving aerodynamic bodies.

It is hoped that opportunity will be given, at a later date, for bringing the subject more fully before the Society and also for describing the Thurston Rotor Ring for reducing the head resistance and increasing the cooling of air-cooled engines.

The writer thanks the authorities of the Air Ministry, N.P.L. and R.A.E. for valuable assistance and for permission to publish the diagrams shown in Figs. 1, 2, 3, 4, 5 and 6.

(EDITORIAL NOTE.—In the February issue of the Journal there will be published, by permission of the Air Ministry, Report No. B.A. 1083, "Wind Tunnel Test of a R.A.F. 28 Aerofoil with Thurston Rotors," by A. S. Hartshorn, B.Sc., and C. Callen, giving the results of lift over an incidence range for 86 different arrangements of wing and rotors, and drag for 19 different arrangements.)

FIFTY YEARS AGO

BY

W. O. MANNING, F.R.AE.S.

In the year 1884 the annual meeting of the Aeronautical Society was held in the rooms of the Society of Arts on the 2nd July. In those days the Society held one meeting only each year, and there were usually three or four papers read. On this occasion, the chairman was Mr. James Glaisher, F.R.S., and in his opening address he referred to the little progress which had been made during the past year, but drew consolation from the fact that there were still many earnest workers actively employed who were working more persistently and more perseveringly than ever. He also stressed the importance of experiment, stating that although the experimenter might not succeed, he could not make any experiment without increasing our knowledge in the way we desire it to be increased.

The Proceedings were continued by a paper by Captain Thomas Griffiths on a Light and Economical Motor for Propulsion in Air. The paper described a method of propelling aircraft by means of jet propulsion. At this date it is not surprising that the author did not know very much about the principles involved and his suggestions were hardly practicable, but his paper is an early reference to a method of propulsion which is still receiving the attention of inventors and which may be of importance in the future.

This paper was followed by one by Mr. S. W. Hollands, of Chatham Dockyard, entitled " Artificial Flight Attainable." Although he did not describe an actual apparatus he was convinced that the future of flying lies in a machine of the aeroplane type which he called an *avitor*. His views on what such a machine should be able to do were sound, and he stated them as follows:—

" First the ability to raise itself and its freight from level ground by its inherent power only and to propel itself in any direction by the same means.

" Secondly, to offer but comparatively small obstructive surface to the wind, so as to be but slightly affected by air currents. Thirdly, to be so constructed that, in the event of the motor breaking down or suddenly stopping, the machine will not fall precipitately to the earth."

He went on to suggest precautions against fire in the air, recommending that the entire avitor be constructed of fireproof material, and suggested that its top speed should be at least comparable with the fastest land vehicles.

His views are perfectly sound to-day.

This was followed by a paper by Mr. C. A. Barry on the " Possibility of Man-Flight," which deals with what we should call to-day man power flight, and contains nothing of great interest. When this paper was over the Chairman drew attention to a Mr. Linfield who was present and who, it seems, had constructed an aerial machine which had been seen by many present. The only information given with regard to this apparatus was that it " almost filled the room." But Mr. Linfield had not only made an aerial machine, but he had persuaded the Great Western Railway to allow him to test it at speed behind a locomotive, and the Chairman had a photograph of the locomotive and the machine which he passed round the room.

Mr. Linfield stated that the experiment was carried out between West Drayton and Staines on the 29th August, 1883, and that the weight of the machine was 240lbs., the speed being about 40 miles an hour. The force neces-

sary to lift the machine was 24lbs. The details are scant, but there is a reference to a tow rope and also to the effect of a side wind, which caused the apparatus to veer so that it narrowly missed several telegraph posts. After this description he was cross examined by the Chairman as follows:—

The Chairman: Did the machine rise?

Mr. Linfield: Yes, a little.

The Chairman: Did it rise entirely from the carriage?

Mr. Linfield: Yes, perfectly free.

The Chairman: What was the space between?

Mr. Linfield: The height depended on the length of the tow rope.

The Chairman: Your machine was in immediate contact with the tender?

Mr. Linfield: No; there were three carriage trucks between the machine and the tender. The tow line was between 14 and 15 feet.

The Chairman: That is not shown (in the photograph).

Mr. Linfield: No, it is not.

The Chairman: That is a pity.

Mr. Linfield: It was an utter impossibility to take it at the speed the train was running.

The Chairman: Photographs are taken now with the train going 40 miles an hour.

The Chairman: You consider the experiment successful?

Mr. Linfield: Yes; certainly.

The Chairman: It is something to know that the whole machine has been raised from the ground by the velocity of the air in meeting it.

It would be most interesting to have some further particulars of this experiment, certainly the first carried out on an aerial machine at such a high speed and on a railway. There is no reference to Mr. Linfield's machine in any reference book I have been able to consult and the Society would be most grateful to any reader who could provide the missing information. A copy of the photograph would be of the greatest possible interest.

There followed a paper by Mr. Breary on "Conjoint Gas and Mechanical Action as Applied to Flight," describing some experiments with flat surfaces and air, and the meeting then terminated.

There was little discussion at the meetings in those days as may be gathered from the fact that it was possible to take all these papers in one evening. Usually the Chairman made a few congratulatory remarks, asked the author a question or two, and then called on the next speaker.

1884

The most important aeronautical event of this year was unquestionably the successful trial of the French dirigible "La France." This was the first aerial machine to make a voyage in the air with a human crew and return to its starting point without alighting. This it accomplished on the 9th August, 1884.

The dirigible left Chalais-Meudon at four o'clock in the afternoon of that day and flew in the direction of Châtillon, turning right so as to pass close to Villacoublay. Then the turn was increased and the course altered to the direction of the starting point, which was reached about twenty-three minutes after the start, during which period the machine had flown about $4\frac{3}{4}$ miles; giving an average speed of about $12\frac{1}{2}$ miles an hour. The landing was uneventful and several further flights were made.

A few details of this dirigible may be of interest. It had a cubic capacity of about 66,000 cubic feet, a length of 178 feet, and a maximum diameter of 27 feet 6 inches, and was driven by a Krebs electric motor which developed 8 h.p. at a speed of 3,600 r.p.m. A reduction gear was fitted so that the pro-

peller speed was 50 r.p.m. The motor weighed about 210lbs., so the power weight ratio was about 26lbs. per h.p.

The current was generated by a primary battery containing chromic and hydrochloric acids, and the electrodes were of platinised silver and zinc. This battery weighed 880lbs., so that the power weight ratio of the entire power plant was about 136lbs. per h.p. It should be stated that Captain C. Renard was responsible for the general design of the dirigible while the power plant was designed by Captain R. A. Krebs, and that these two were alone on board during the trial.

CORRESPONDENCE

Metal Construction

To the Editor of the Journal of the Royal Aeronautical Society.

Dear Captain Pritchard,—In the issue of the Royal Aeronautical Society's Journal for August, 1933, the following appears on page 690:—

> "The first all-metal aeroplane constructed in this country was the 'Short' Silver Streak, which appeared in 1919."

I do not think this is correct. I have an impression that in the early years of the war an all-metal aeroplane was constructed of tubes, but it was not a success, owing to its weight and lack of adequate strength.

I know, however, that in 1918 my firm, the Steel Wing Company, successfully completed in steel the wings for a machine known as the MR. 1, and this machine was flown in the latter part of 1918.

As you know, the construction of fuselages in metal was a comparatively easy problem to solve, the difficulty in metal aeroplane construction was to produce a wing structure which would equal the performance of wooden wing structure in weight and strength.

The Steel Wing Company solved this problem by the use of corrugated strip in 1916.

I have for several years ceased to have any connection with the aeroplane industry, and in consequence have not access to the necessary records to verify the statement, but I believe it to be the fact, that a form of steel wing, designed and made by my late firm in 1922, is, with very slight modifications, still in use in the D.H. 9A and its successors, the Wapiti and Wallace machines, *i.e.*, the Steel Wing Company's designs and method of construction for steel aeroplane wings has not, in any essential particular, been improved on in more than ten years.

I have also heard, but I cannot verify the fact, that one at least of the machines which flew over Everest had this design of wing, and from such casual inspection as in recent years I have been able to make of present-day aeroplanes, it seems to me that most of them embody in one form or other the principles on which the Steel Wing Company solved the problem of metal wing construction nearly seventeen years ago.

I have no desire for the limelight, but I think it is only fair that credit should be given where it is due, especially to the men who, as designers or engineers,

helped me to solve the problem of the construction of aeroplanes in metal. I have especially in mind Mr. Donald Emby, Whit. Exb., Mr. Brian Martin, B.Sc., and Mr. Leo Martin.

Perhaps you could in some way put this matter right, if only in the interests of historical accuracy, which I think concerns the R.Ae.S.

Yours very sincerely,

DERMOT J. MOONEY.

(Mr. Mooney's letter is one of considerable importance and interest and correspondence on the subject of metal construction in its early stages is invited. As Mr. Mooney remarks, the problem of metal fuselages was comparatively easy to solve. M. Esnault-Pelterie took out patents for a welded steel tubular construction and Mr. (now Major) A. R. Low incorporated a considerable number of improvements, as early as 1911-12, though handicapped by the lack of a sufficiently high tensile steel. In the war, round about late 1916--early 1917, speaking from memory, the Admiralty carried out tests with steel spars. In a paper read before the Society by Dr. A. P. Thurston in May, 1919, detailed account of the work done up to that date is given. In the discussion Major Low claimed that he built the first all-metal machine, but the weight of the wings was too great and they had to be scrapped for wood. Mr. Mooney also drew attention to the fact that none of the construction actually described in Dr. Thurston's lecture had been built into a complete metal wing, while some of the all-steel wings of his own company had been actually tested in flight.

In his lecture before the Society in 1923 Professor H. Junkers describes his method of construction and his first steel aeroplane, the J.1, which, according to the official report of the German Army authorities in 1916, had a speed of 170 km. per hour, with an engine of 120 h.p. and total weight of 1,010 kg. "The construction of my metal aeroplanes is based on a patent, granted to me as far back as 1910," to quote from the lecture. That patent shows the form of construction, but does not state it is in metal. In 1917 was completed the J.4 in duralumin.—EDITOR.)

REVIEWS

First Over Everest

By Air Commodore Fellows, L. V. Stewart Blacker, Col. P. T. Etherton, Sq.-Ldr. the Marquess of Clydesdale, M.P., and Geoffrey Barkas. Published by John Lane. Price 12/6.

The urge to explore the unknown is a potent force which attacks some men of all nations, but especially the British. It was possibly responsible for the advance across Europe of the Aryan invaders in the dawn of history, and it was certainly one of the chief motives which led to the exploration of the seas of the world in Elizabethan times. Nowadays the opportunities for indulging in exploration are more limited, but that the urge is still there is proved by the frequency of Polar expeditions and by this flight.

In olden times the result of expeditions of this type was frequently the annexation of previously unknown lands, nowadays the result desired is the acquisition of more knowledge about the earth, and of this latter type the Everest Expedition is an excellent example. Everest is not only the highest mountain in the world, but it lies in a region which was almost unexplored, though one or

two of the highest peaks on the range had been examined through instruments from a distance, so that their height and position was known.

As Mount Everest lies on the frontier between Tibet and Nepal, there were considerable political difficulties in the way of exploration, as both these States object to the entry of foreigners. It was found possible, however, to obtain permission to operate from Nepal, though the permission given was restricted to the making of two flights over the mountains. These resulted in the taking of numerous photographs of Everest itself and the surrounding district which have materially increased our knowledge of the geographical features of the country.

This book gives an excellent description of the whole history of the expedition from its inception, and describes in detail the manner in which the difficulties encountered were overcome. For the purpose of the flight the aircraft had to fly at over 30,000 feet in a temperature of $-45°C$. This not only meant the provision of oxygen and heating for the pilot and observer, but provision for the heating of the cameras and other special gear, as without this precaution celluloid film would have lost its flexibility and the lubricating oil would have frozen solid. The success of the expedition was very largely due to the careful preparations made in England before the departure, and to the great care with which the working of every part was checked.

There is an interesting account of the journey out and a description of various attempts which had previously been made to survey the Everest district, and one is also told something about life in Nepal, but the main interest of the book consists in the description of the painstaking preparations, with the deserved result that the culminating flights were practically free from trouble. In the organisation of the ground work this expedition was a model of its kind.

The book includes some 50 photographs, many of which are of Everest and its neighbourhood, but there is, curiously enough, no photograph of the Westland aeroplanes which made the flights possible, though parts of them appear as backgrounds in certain of the photographs. It also contains a well-deserved tribute to Lady Houston, whose generosity made the expedition possible.

The book should be in every aeronautical library.

Jane's All the World's Aircraft

1933 edition. Edited by C. G. Grey, published by Sampson Low. Price £2 2s.

The 1933 edition of this book resembles the previous editions in style and make-up, and well maintains its reputation as a reference book which no one interested in aeronautics can afford to be without.

There has been a continued improvement during the past year in the design of aircraft, especially in the reduction of unnecessary resistance—a matter which has been materially helped by the development of the retractable undercarriage. The book illustrates the progress that has been made in America in the design of high-speed commercial aircraft, culminating in types having top speeds of over 200 m.p.h. All over the world the performance of aeroplanes is increasing, and it is interesting to note that this increase is due more to improvement in aerodynamical design than to improvements in engines.

The military types are improving in the same direction, but in this case it is we who lead the world, though there is obviously an attempt being made by other nations to produce machines as fast as our own. It would seem that machines for private owners show less advance than the other types, though some especially fast light aircraft have been produced during the year; much of the increase in speed has been obtained by fitting larger engines.

Engines themselves show a steady advance in design with a tendency to the increased use of forced induction in the larger types. There is also an increased interest being shown in the compression-ignition cycle, which may be expected to continue to increase in the future.

There are so many different types of propellers now being developed, variable pitch and others, that it is hoped that it may be possible to devote a section to them in future editions but, as it is, the book is an invaluable record of the progress of aeronautics.

Wings of War

By Rudolf Stark. Published by John Hamilton. Price 7/6.

This book, which has been translated from German by Mr. Claud W. Sykes, describes the adventures of the author as a scout pilot during the 1918 period of the war. His accounts of the various fights in which he was engaged do not differ appreciably from those described by the English pilots who have written books on this subject, in fact any one "dog fight" must have been very much like any other. But the book becomes more interesting when the author deals with the period which followed the German failure to capture Amiens, for it was then clear to every intelligent German that the war was lost.

That demoralisation had set in amongst the civilian population was clear to the author when he went home on leave, and this demoralisation eventually, spread to the fighting forces, though certain formations, such as the author's, retained their discipline and their fighting spirit to the end. The book concludes with a picture of complete disorganisation—officers removing their badges of rank to avoid being assaulted by their men, soldiers' and sailors' councils, red flags, etc.—and it is evident that the German Army had practically ceased to exist.

There is little information on technical subjects, but it is of interest to note that the Staffel did not like going back to Pfalz biplanes of the ordinary wire-braced type after having used the unbraced Fokker machines. They considered that the Pfalz "looked too much like a harp." Even the sergeants grumbled "because of the trouble the bracing was going to make for them," and the mechanics cursed "because of the extra work to assemble and dismantle." This may be a point that deserves attention in the design of our own Service aircraft.

The book is interesting as a description of the last phase of the war from the point of view of the German Air Force, but is marred by the curious staccato style used in many parts. But this may be an attempt by the translator to copy in English some peculiarity of the German version.

Aeronautical Index to Aeronautical Technical Reports

Prepared by the Society of British Aircraft Constructors, and published by the Royal Aeronautical Society. Price 5s.

There are so many wind tunnels being operated in the world, all of whom turn out technical data concerning aeronautics, and so many scientists publishing information on this subject that it is absolutely impossible for those occupied in aircraft design to read more than a fraction of the matter available. There is always, therefore, a danger that a technician interested in some particular feature of design may miss information which may be of the utmost importance to his work.

This book, which deals mainly with 1932, in intended to keep those interested in touch with current progress in aeronautical and engine research by publishing a list of all papers dealing with this subject, a note dealing with the subject of the paper, and information stating where the paper can be found, the whole

arranged under main headings in alphabetical order. It is therefore easy for anyone interested to look up a main heading and obtain all the papers published dealing with his subject.

The English and American papers are indexed separately from the papers from other countries on account of language difficulties, and some idea of the scope of the book may be gathered from the fact that there are approximately one hundred societies' journals and other publications referred to. The references to the R.Ae.S. Journal are especially numerous.

A book of this kind is invaluable to the designer or technician, as it would be completely beyond his power to keep in touch with progress without it, but there is some scope for improvement with regard to the arrangement of the papers under the headings which might well receive attention in the next edition. It often facilitates reference if the same paper is referred to under more than one heading.

The 568th Lecture read before the Royal Aeronautical Society since its foundation January 12th, 1866.

PROCEEDINGS

THIRD MEETING, FIRST HALF, 69TH SESSION

The Third Meeting of the first half of the 69th Session of the Royal Aeronautical Society was held in the lecture theatre of the Royal Society of Arts, on Thursday, November 16th, 1933, when a paper on " Problems Involving the Stiffness of Aeroplane Wings " was presented by Dr. H. Roxbee Cox. In the chair, Major J. S. Buchanan, C.B.E., F.R.Ae.S. (Member of Council).

The CHAIRMAN: As long as we in this country were content to build biplanes of moderate speed, the problem of the stiffness of the wings was perhaps relatively unimportant; but having regard to the very greatly increased speeds demanded in modern times, and the more general use of the monoplane, the question of the stiffness of the structure had become one of the important problems which the aeroplane designer had to deal with. Dr. Roxbee Cox was one of those who had been concerned with the problem of the stiffness of wings for some time past.

Dr. Roxbee Cox then presented his paper.

PROBLEMS INVOLVING THE STIFFNESS OF AEROPLANE WINGS

BY

H. ROXBEE COX, PH.D., D.I.C., B.SC., A.F.R.AE.S.

§1. *Introduction*

An aircraft may reasonably be said to be structurally safe if it is known that during the manœuvres which it is likely to perform

(i) The stress in no part of the essential structure approaches the failing stress of the material,

(ii) It does not become unstable or uncontrollable on account of structural distortion.

I intend to discuss in this context the wing structure of the aeroplane.

For many years it was felt both in the design and airworthiness approval of the majority of aeroplane wing structures that the main responsibility for attempting to secure the former desideratum could rest upon the determination of the stresses induced in the wing structural material by load systems appropriate to a rigid aeroplane in certain conditions defined by specified combinations of flight attitude, acceleration, and factor of safety. These combinations—familiarly referred to as the C.P. forward, C.P. back, nose-diving and inverted flight cases—are designed to produce for a particular aeroplane a range of steady load systems which is more severe on the structure than the range of load systems corresponding to the manœuvres contemplated for the aeroplane.

The success of any structure designed to carry varying loads depends upon its qualities of strength and of *stiffness*. The standard loading cases just mentioned merely provide measures of strength under constant loads, and it has

long been recognised in consequence that, while indispensable, they could not be the only tests of the staunchness of a wing structure. For they take no account of the distortion of the wing structure which must necessarily occur in flight. This distortion, which is dependent upon the magnitude and distribution of stiffness, may be of two kinds. It may be uni-directional and of such magnitude that the conception of the aerodynamic loading as being similar to that for a rigid wing is no longer sufficiently approximate. Or it may be oscillatory, when it is termed " flutter." In connection with the first desideratum, neglect to consider both types of distortion may result in a stress failure. In connection with the second desideratum, the uni-directional distortion may affect stability or lateral control.

It becomes necessary to determine, therefore, what stiffness characteristics a wing structure should have if flutter, undue loss of lateral control, and undue lack of stability are to be avoided and if the assumption of a rigid wing for the purpose of determining aerodynamic load systems is to be sufficiently approximate. Some progress towards this end, which I shall outline in §§2, 3, 4 and 5, has been made. The investigations described indicate the great importance of providing high torsional stiffness in wings, so in §§6 and 7 respectively I shall deal with the torsional stiffness properties of conventional wings and the effect of providing high torsional stiffness on methods of *strength* calculation.

In what follows, bracketed indices refer to papers of which the authors and titles are given in Appendix III.

§2. *Wing Stiffness in the Prevention of Wing-flutter*

The problem of flutter has been discussed in great detail in two monographs[1, 2] by Mr. Frazer and Dr. Duncan, of the National Physical Laboratory, who were able to deduce from their theory certain design recommendations. Of these recommendations, some were in the form of precise statements needing little amplification, but others were necessarily of a qualitative nature. Among the latter was the recommendation " All elastic stiffnesses as large as possible," which, if it is to have practical value, needs quantitative extension.

In the case of a particular aeroplane, it is possible by means of the theory of wing flutter developed by Frazer and Duncan, to determine quantitatively the elastic stiffnesses necessary if flutter is to be avoided, provided that an elaborate series of tests and calculations is made. The procedure is, however, too expensive and laborious to be used either in design or in the formulation of a quantitative rule.

An alternative method which has been attempted in an effort to determine wing stiffness values sufficient to preclude wing-aileron flutter is of a statistical and less approximate nature. The procedure is to correlate the elastic stiffnesses of the wings of existing aeroplanes with their observed behaviour with regard to flutter, noting and allowing for such flutter prevention features of design as may be embodied in them. The adequacy of the wing stiffnesses of a new design can then be judged by comparing them with the information obtained.

§2.1. In developing this procedure, it was necessary first to determine

(i) In what circumstances different aeroplane wings could be considered comparable,

(ii) The criteria by means of which quantitative comparison could be made.

§2.2. It was found possible to formulate a theoretical argument if the wing-aileron systems compared, though of different aspect ratio, had

(i) Corresponding spanwise dimensions in plan in constant ratio,

(ii) Corresponding chordwise dimensions in plan in constant ratio,

(iii) Wing sections similar,

(iv) Distances from leading edge of flexural axes, transverse principal axes of inertia, and axes of independence respectively constant fractions of the corresponding chords,

(v) Similar distributions of mass,

(vi) Similar distributions of elasticity.

§2.3. With these provisos, it was possible to deduce by dimensional theory that

(i) For a motion involving flexure of the wing and flapping of the aileron the oscillatory instability (flexural-aileron flutter) speeds are related for wings for which δ/c is constant by

$$(1/V)\sqrt{(l_\varphi/s^3)} = \text{constant}, \quad . \quad . \quad . \quad . \quad (1)$$

(ii) For a motion involving torsion of the wing and flapping of the aileron, the oscillatory instability (torsional-aileron flutter) speeds are related for wings for which $\delta/c = \text{constant}$ by

$$(1/V)\sqrt{(m_\theta/sc^2)} = \text{constant}, \quad . \quad . \quad . \quad (2)$$

where s = span of the wing (feet),

c = mean chord of wing (feet),

δ/c = " wing density "

$$= \frac{\text{wing wt. per unit area}}{\text{mean chord}} \text{ (lbs./feet}^3\text{)},$$

V = airspeed (ft./sec.),

l_φ = typical flexural stiffness (lbs. feet/rad.),

m_θ = typical torsional stiffness (lbs. feet/rad.).

§2.4. Strict recognition of the six provisos above would in practice prohibit any comparison of wings ever being made. Further investigation into the magnitudes of the errors involved in departing from the strict interpretation, however, has indicated that

(i) (i) and (ii) of §2.2 may be taken to mean that monoplanes must be considered separately from biplanes, and that aeroplanes with unusual wing or aileron proportions must be excluded from the comparative data,

(ii) (iii) and (iv) of §2.2 may be ignored,

(iii) Within the classes given in (i) above, (v) of §2.2 is approximately obeyed,

(iv) The variation of distribution in elasticity sometimes must occasion a sub-division of the classes of (i) above. Thus, for example, while many externally braced monoplanes show curves of wing distortion under tip loading similar to the curves for cantilever monoplanes, others differ so considerably as to form a class of their own.

§2.5. As an example of the practical application of the conclusions reached, we may consider the comparison of a number of typical monoplanes. Their several distributions of flexural elasticity may for practical purposes each be represented by the flexural distortion produced by a load placed near the wing tip.[3] Their distributions of torsional elasticity may each be represented by the torsional distortion produced by a torque applied near the wing tip. For twenty-six monoplanes for which the necessary information was readily available the flexural distortion diagrams fell into two groups represented by the envelopes A and B shown in Fig. 1. For these monoplanes, consideration of torsional distortions produces the same classification. It was considered that the monoplanes in each group were sufficiently similar elastically to be compared among themselves.

The next step was to make use of the comparative criteria of §2.3. To obtain these, values for l_φ and m_θ were needed. l_φ was obtained in each case by applying a load W near the wing tip at such a position on the chord that the loaded section deflected without twisting and measuring the deflection Δ of the

loaded section. Then if the loaded section, chosen normally near to the outermost aileron hinge, is distant s from the wing root,

$$l_\varphi = Ws^2/\Delta \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

m_θ was obtained in each case by applying a torque T in the same section near the wing tip and measuring the twist Θ at that section; then

$$m_\theta = T/\Theta \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

In calculating the values of $(1/V)\sqrt{(l_\varphi/s^3)}$ and $(1/V)\sqrt{(m_\theta/sc^2)}$, V was taken as the highest speed at which the aeroplane could fly. In the cases of aeroplanes on which wing flutter was experienced, this was the flutter speed. The values of $(1/V)\sqrt{(l_\varphi/s^3)}$ and $(1/V)\sqrt{(m_\theta/sc^2)}$ were then plotted against wing density, producing Figs. 2 and 3.

In the diagrams, the aeroplanes which have experienced wing flutter are distinguished from those which have not, and those in which the anti-flutter device of mass-balancing is incorporated are distinguished from the rest.

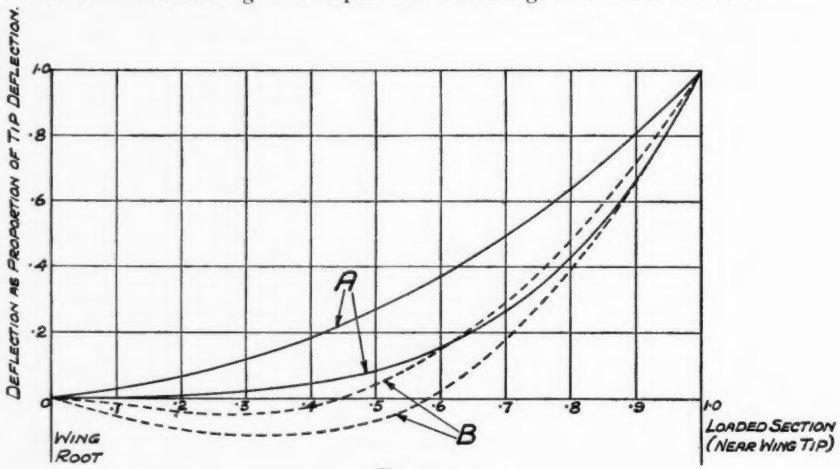


FIG. 1.

Envelopes of diagrams of wing flexural distortion under load applied near wing tip for 26 typical monoplanes.

In both Fig. 2 and Fig. 3, a full line has been drawn so that the flutter cases lie below it. These lines, whose characteristics have received valuable theoretical support,[4] therefore provide quantitative guides to the stiffnesses which should be provided if flexural-aileron and torsional-aileron, and, by inference, flexural-torsional-aileron flutter are to be avoided when no anti-flutter design feature is used. A dotted line has also been drawn in each diagram through the lowest points representing aeroplanes employing mass-balanced ailerons. Monoplanes plotting above this line are consequently probably safe from wing-aileron flutter, but it does not follow that monoplanes plotting below it are unsafe. The dotted lines are therefore merely representative of the low limit of current practice.

The development of diagrams of this kind is clearly of value, and others dealing with biplanes are given in R. & M. 1505.

Such diagrams all indicate that the minimum stiffness criteria values increase with wing density and that the provision of aileron mass-balance, or, in the cases of biplanes, arranging for at least half the aileron span to be inboard of the outer gap struts, permits the use of lower wing stiffnesses than when no anti-flutter

⊙ Indicates 'no flutter experienced'. ⊡ Indicates 'flutter experienced'
↑ Indicates 'wings with mass-balanced ailerons'.
_____ Plottings for wings without mass-balanced ailerons should lie above this line.
_ _ _ _ _ Plottings for wings with mass-balanced ailerons probably need not lie above this line.
Speed V used in calculating criterion values is highest at which aeroplane can fly. In values represented by ⊡ points, this is flutter speed.

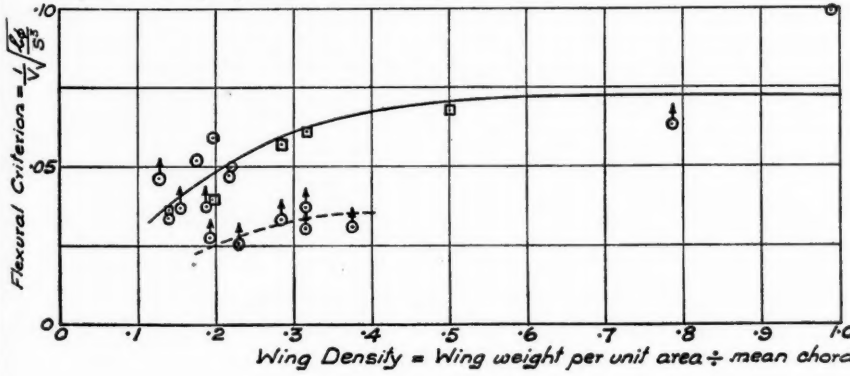


FIG. 2.

Wing flexural stiffness flutter criteria for monoplanes falling into the group defined by envelope A in Fig. 1.

⊙ Indicates 'no flutter experienced' ⊡ Indicates 'flutter experienced'.
↑ Indicates 'wings with mass-balanced ailerons'.
_____ Plottings for wings without mass-balanced ailerons should lie above this line.
_ _ _ _ _ Plottings for wings with mass-balanced ailerons probably need not lie above this line.
Speed V used in calculating criterion values is highest at which aeroplane can fly. In values represented by ⊡ points, this is flutter speed.

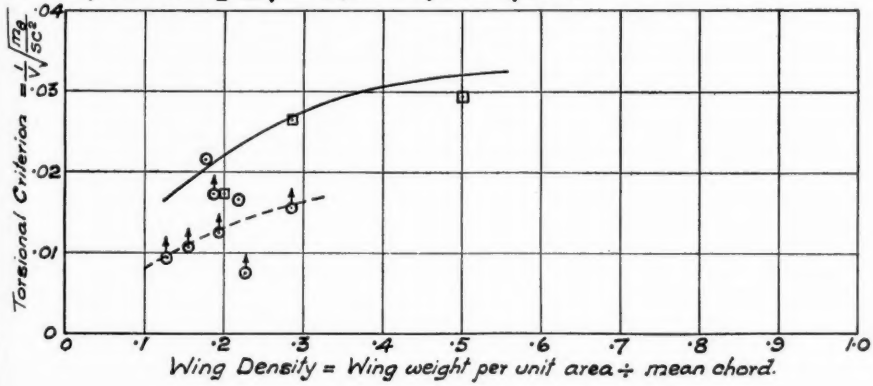


FIG. 3.

Wing torsional stiffness flutter criteria for monoplanes falling into the group defined by envelope A in Fig. 1.

device is employed. It should be emphasised, however, that there are limits to the safe reduction of wing stiffness and that flexural-torsional wing flutter is always a possibility. Aileron anti-flutter devices are potent only in preventing wing-aileron flutter, and have little influence on flutter of the wing only.

§2.6. No authenticated case of pure wing flutter in flight is known to me, but with the building of larger and larger monoplanes and the more and more economical use of material, the difficulties of providing adequate stiffness increase. It can be shown[5] that in legislating against pure wing flutter the ratio of torsional to flexural wing stiffness should be as high as possible, and that the safest way to ensure this is to provide *high torsional stiffness* rather than low flexural stiffness. I cannot, unfortunately, give minimum stiffness figures for prevention of pure wing flutter, but they are clearly lower than those indicated by the dotted lines in Figs. 2 and 3.

§3. *Wing Stiffness in the Prevention of Loss of Lateral Control*

§3.1. When the ailerons of an aeroplane are moved in flight, twisting moments are induced on the wings. These moments normally cause the wings to distort torsionally in such a way as to produce a smaller rolling moment than would have been obtained had the wings been effectively rigid. In some aeroplanes this effect has been so serious that the ailerons were completely ineffective; in others, it has been even worse and reversal of the lateral control has occurred.

§3.2. I propose to consider first how the critical speed at which complete loss of lateral control occurs can be calculated for any wing-aileron system.[6]

First of all some speed V_1 and some small aileron angle ξ are chosen. Next some arbitrary curve of torsional wing distortion is assumed and the aerodynamic loading corresponding to this distortion, V_1 and ξ is determined.

The torsional distortion due to this aerodynamic loading is then calculated, and a second approximation to the aerodynamic loading is obtained from this distortion, V_1 and ξ.

The distortion due to the second approximation to the aerodynamic loading is next found, and the process of successive approximation is continued until the distortion due to the aerodynamic loading is indistinguishable from the distortion producing that aerodynamic loading. Having thus obtained the distortion consequent upon an aileron angle ξ at a speed V_1, the calculation of the rolling moment corresponding follows.

In the same way the rolling moment for the same aileron angle ξ is calculated at speeds V_2, V_3, . . . and a curve of rolling moments against speed is plotted. This curve defines a speed V_r, for which the rolling moment is zero, and this is the critical reversal speed.

In practice it should never be necessary to choose more than three speeds V, and the successive approximation process at each speed does not normally extend beyond the third approximation.

The procedure is very accurate and is applicable to any kind of wing, but it is laborious and requires that the wing structure shall have been designed before it can be applied.

§3.3. For the last two reasons it is clearly desirable that a different method of determining critical reversal speed, or, alternatively, of finding the torsional stiffness which must be provided to avoid loss of lateral control, is required.

Such a method is available.[7] Its theoretical development depends upon a device known as the " semi-rigid wing." This device appears first to have been used by Frazer and Duncan in their flutter work, and has several useful applications.

For the present purpose, a semi-rigid wing is defined as one in which, whatever the magnitude and distribution of the loading,

(i) Purely flexural deflections along the span bear constant ratios to one another,

(ii) Purely torsional deflections along the span bear constant ratios to one another,

(iii) Absolute deflections depend only on the equivalent loading actions at some reference section and the variations of flexural and torsional stiffness measured at that section with flexural and torsional deflections there,

(iv) The aileron displacement relative to the wing at any section is invariant with wing deformation.

Wing distortion shape being, in this type of wing, independent of the distribution of aerodynamic loading, the successive approximation process just described for an elastic wing does not arise, and a direct formula for reversal speed is obtained. This is

$$V_r = K\sqrt{(m_\theta/\rho s c^2)} \quad . \quad . \quad . \quad . \quad . \quad (5)$$

where s = distance from wing root to wing tip (feet),

c = mean wing chord (feet),

ρ = air density (slugs/feet^3),

m_θ = torsional stiffness of wing at reference section (lbs. feet/rad.),

and K is a "reversal coefficient," depending upon the wing section, the plan forms of wing and aileron, the position of the reference section, and the distributions of wing twist and aileron angle along the span. Its quantitative definition is rather elaborate and is given in Appendix I. If this formula is to be applied to the calculation of the critical reversal speed for an elastic wing then it is clearly necessary to find rules defining a semi-rigid wing equivalent as regards its loss of lateral control characteristics to the elastic wing.

§3.4. This has been done. At the outset, the assumptions made were that the semi-rigid wing had the same wing and aileron plan form and the same wing section as its elastic pattern. It remained therefore to determine

(*a*) A reference section for both wings at which the semi-rigid wing should be made to have the same torsional stiffness as the elastic wing,

(*b*) The distribution of wing twist which the semi-rigid wing should have,

(*c*) The distribution of aileron angle along the span which the semi-rigid wing should have.

There is no obvious logical connection between the semi-rigid and the elastic wing, so that the connection was not sought theoretically, but empirically. To begin with, three elastic wings of rectangular plan form and with rectangular ailerons were considered.[7] The critical reversal speeds of two of these, of 9ft. span, were determined in the wind tunnel[8] and the critical reversal speed for the third was determined by the successive approximation method already described. The semi-rigid equivalent was in each case supposed to have a linear distribution of wing twist with a constant aileron angle. Reference sections at the wing tip and at mid-aileron were tried and, as seen from Table I, using the former the formula gave in each case a remarkably close approximation to the true critical reversal speed.

TABLE I.

CRITICAL REVERSAL SPEEDS OF WINGS OF RECTANGULAR PLAN FORM.

Wing No.	Theoretical Critical Reversal Speed in f.p.s. Assuming Reference Section at Wing Tip.	Mid-Aileron.	Actual Critical Reversal Speed in f.p.s.	Speed in Previous Column Obtained by
1	55·4	53·5	55	Wind tunnel experiment.
2	74·5	87·5	90	Wind tunnel experiment.
3	151·5	182.2	187	Successive approximation calculation.

This encouraging result led to the adoption of a reference section at mid-span of the aileron for investigations into the determination of (*b*) and (*c*).[9]

The variation of the reversal coefficient as defined in Appendix I with the law of twist distribution is shown in Table II for various degrees of wing taper and aileron span. Where y is the distance of a general point from the wing root and $y=ns$ defines the reference section in terms of the span s, the laws of twist distribution considered were of the form

$$\theta \propto (y/ns)^u \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

TABLE II.

VARIATION OF REVERSAL COEFFICIENT WITH LAW OF WING TWIST FOR AN ELLIPTIC WING IN WHICH THE AILERON CHORD IS EVERYWHERE ONE QUARTER OF THE WING CHORD AND THE REFERENCE SECTION IS AT MID-SPAN OF AILERON.

Aileron Span / Wing Semi-Span	Reversal Coefficient when $\theta \propto (y/ns)$	$\theta \propto (y/ns)^2$	$\theta \propto (y/ns)^3$
.6	2.05	2.16	2.14
·5	2.26	2.46	2.54
·4	2.51	2.81	3.00

In so far as the law chosen should represent the shape at reversal of control of an elastic wing, $u=2$ probably gives an approximation applicable to an average wing while $u=3$ gives a far more exaggerated shape which can fairly be considered as a limit (Fig. 4). Even over this wide range K is, from the table, insensitive to the assumed distribution of wing twist. There appears in consequence to be no objection to taking the simplest assumption of $u=1$ for wing twist in calculation, that is, to assuming the semi-rigid wing to distort linearly.

With regard to (*c*), it is easy to prove that the reversal coefficient is independent of the distribution of aileron angle along the span if the wing twist

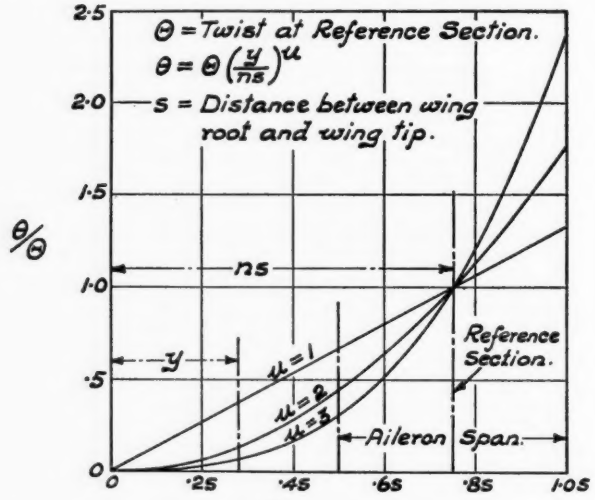


FIG. 4.

Semi-rigid wing torsional distortion shapes selected for investigation in studying estimation of critical reversal speed.

distribution is assumed linear. When the wing twist distribution is assumed cubic (*i.e.*, $u=3$), and the aileron angle is taken to be twice as great at mid-aileron as at the aileron ends, the error involved in assuming the angle constant is only 1 per cent. In calculations, therefore, this assumption is justified.

§3.5. We are led to believe, therefore, that the critical reversal speed of an actual wing is given to a good degree of approximation by the critical reversal speed of a semi-rigid wing in which

(i) The aerodynamic characteristics are the same as for the elastic wing,
(ii) The reference section is at the mid-span of the aileron,
(iii) The torsional stiffness measured at the reference section is the same as that of the elastic wing measured at the corresponding section,
(iv) The law of distribution of wing twist is linear,
(v) The aileron angle relative to the wing is constant along the aileron span.

We have already seen that this procedure is successful for rectangular plan form wings with normal elastic characteristics. It has also been applied to wings tapering in plan and with more exaggerated distributions of elasticity. As an example, the critical reversal speed for an elastic wing in which the tip chord was .3 of the root chord and which was unusually flexible in the region of the aileron was calculated by the precise successive approximation process and from the semi-rigid wing analogue; the error involved in using the latter process was shown to be only 2.5 per cent.

§3.6. As the formula (5) in the circumstances defined in §3.3 is applicable to actual wings, it provides a means of finding how different controllable factors influence critical reversal speed. It is immediately clear from the formula that the reversal speed varies directly as the square root of the torsional stiffness of the wing structure, and the advantage of high torsional stiffness is apparent.

Another extremely influential factor, however, is wing taper in plan form. If we imagine a given monoplane wing structure and superimpose upon it wing plan forms of varying degrees of taper but of the same span and area (and hence the same aspect ratio), the reversal speeds of the wings so formed vary with taper as shown in Fig. 5, in which, reading upwards, the curves correspond to

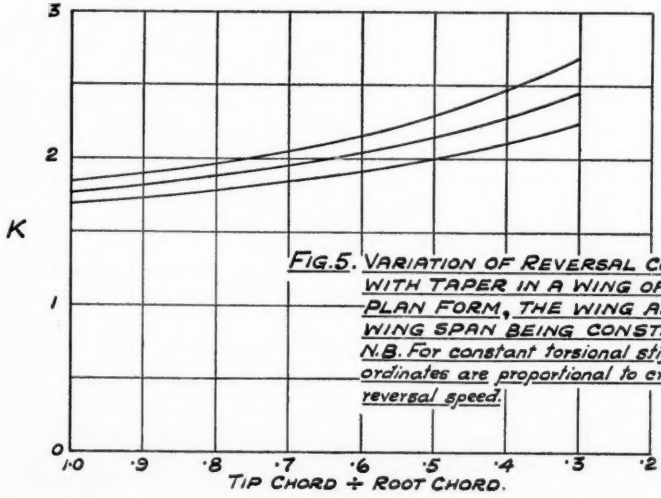


FIG. 5. VARIATION OF REVERSAL COEFFICIENT (K) WITH TAPER IN A WING OF TRAPEZOIDAL PLAN FORM, THE WING AREA AND WING SPAN BEING CONSTANT. (*See* §3.6)
N.B. For constant torsional stiffness the ordinates are proportional to critical reversal speed.

aileron spans of .6s, .5s and .4s. This indicates the advantage in designing to prevent loss of lateral control of a high degree of taper; this is illustrated differently in Fig. 6 where the torsional stiffnesses of wings of constant span and constant area with the same reversal speed are plotted against taper in three curves which, reading downwards, correspond to aileron spans of .6s, .5s and .4s.

§4. *Wing Stiffness in the Prevention of Wing Distortion in Flight*

An aeroplane wing in flight is distorted flexurally and torsionally by gravity loads, by inertia loads, and by aerodynamic loads consistent with the distortion which they are chiefly responsible for producing.

When the strength of a wing is being checked, the aerodynamic loads used are generally those consistent with the wing being undeformed. Consequently the stresses occurring in the wing of an aeroplane in certain conditions of flight may be considerably different from the stresses calculated for those conditions as, although the total lift on the wings may be correctly estimated, its distribution will not be. The error involved in neglecting the effect of distortion is clearly dependent upon the degree of elasticity of the wing. In certain circumstances it is possible for this error to be " on the right side," that is, for neglect of the effects of the elasticity of the wing to provide a " hidden margin of safety." More frequently, however, the " hidden margin " is negative, a circumstance which may have a bearing on certain accidents for which adequate explanation has not been found.

There are available two methods of calculation which give a good approximation to the stresses in a wing when the effect of its distortion under load is allowed for.

One of these is a successive approximation method similar to the one already described in connection with the calculation of critical reversal speed. Starting with the aerodynamic load distribution corresponding to the undeformed configuration of the wing, the distortion due to it and the gravity and inertial loads operating is calculated. Using the aerodynamic loading distribution corre-

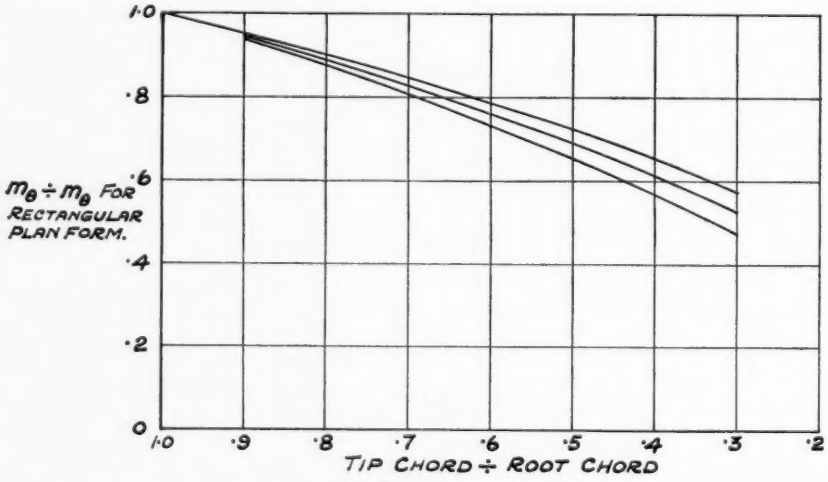


FIG. 6.

Variation with taper of torsional stiffness (m_θ) required to prevent reversal of lateral control for trapezoidal wings of constant area and constant span (see §3.6).

sponding to this distortion, a fresh distortion is calculated. The procedure is repeated until the nth distortion calculated is negligibly different from the $(n-1)$th. Three approximations will generally be found sufficient.

In the second method the aerodynamic load distribution and the wing twist distribution which are consistent are obtained directly by rather involved algebraic methods. The essential procedure is given in R. & M. 1509.[10]

All I have so far implied is that the stresses in a wing in a particular condition of flight may be dangerously greater than the stresses estimated for that condition. That is not all however. On account of its elasticity the structure of the wing may become unstable in circumstances which conventional calculations would indicate to be safe. It is extremely difficult to illustrate this point by reference to actual elastic wings. The point which I wish to demonstrate is, however, conveniently illustrated by making use once more of the semi-rigid wing.

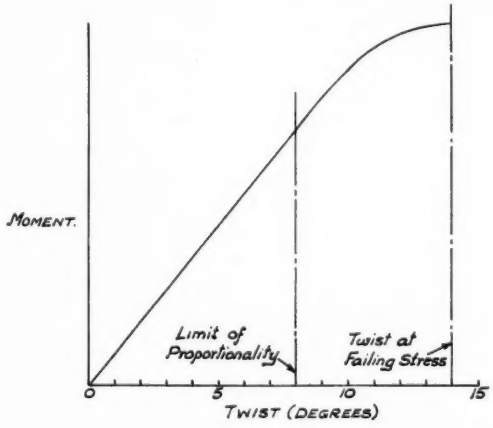


FIG. 7.

Typical relationship between twisting moment and angular distortion measured at a general section of an elastic wing.

Now there is a property of the elastic wing which it is essential to copy in the semi-rigid one in the present instance. If a particular distribution of aerodynamic load is chosen for, say, a mechanical test on a wing, and if the magnitude of this load is increased incrementally, the flexural and torsional deflections at any given section will be proportional to the load so long as all the structural material obeys Hooke's Law and compression members do not bow. As the loading is increased however, sooner or later a stage will be reached at which the material of some unit of the structure passes the elastic limit and enters the plastic state. Thereafter, distortion can no longer be everywhere proportional to loading and, as with further loading more and more of the structural material passes its elastic limit, the rate of growth of distortion with loading increases until at some point the breaking stress is reached.

This characteristic is copied in the semi-rigid wing by hypothesising for it at all sections moment-deflection curves with ordinates proportional to a curve like that of Fig. 7.

Now a semi-rigid wing has the property that forces on it can all be replaced by equivalent forces at a chosen reference section. Its ability to represent

successfully an elastic wing depends upon the judicious choice of this section, and in the problem of reversal of control we found that the best position was at aileron mid-span. In illustrating the effect to which I wish to draw attention, however, I am not concerned to justify any particular choice of reference section, and have chosen in my calculations for Fig. 8, to assume it at the tip of the wing. In these calculations I have also supposed the semi-rigid wing to be such that the torsional distortion at any section is always proportional to the distance of that section from the root and for this wing, once having chosen a value for the torque which if applied at the tip would cause unit angular deflection there, for calculation purposes I could have chosen *any* position for the reference section. Such a wing has been termed a *simple* semi-rigid wing[1] and is best imagined as consisting essentially of two rigid spars connected to their base by springs at their roots. The springs may be supposed to have elastic properties which produce the moment-deflection characteristics of Fig. 7, and in my illustration may be regarded as the critical stress bearing portions of the wing.

In the diagram ordinates are moments measured at the reference section and abscissæ are angles of twist measured there. AOB is the curve relating moment and angular distortion at the reference section. It signifies that for wing tip twists in the range $\pm 8°$, the wing distorts in accordance with Hooke's Law. In the ranges $-14°$ to $-8°$, and $8°$ to $14°$ the distortion is plastic. At $\pm 14°$, rupture of the material occurs. In drawing the rest of the diagram I have imagined the semi-rigid wing to be fitted to an aeroplane nose-diving. I have assumed that whatever its speed, there is no resultant lift on the wing.

If on the diagram a line is drawn connecting aerodynamic moment and angular distortion in a dive at a given speed, the point at which this line cuts AOB defines the angle of distortion which must be occurring at this speed. I shall assume in my illustration that such an aerodynamic line is straight, which is not unreasonable for the range of angular distortion chosen.

Now, as already stated, the usual assumption in calculations is that the aerodynamic loading corresponds to the undeformed wing. That is tantamount to assuming the aerodynamic twisting moment invariant with distortion. If we represent this for a speed of 400 f.p.s. on the diagram, we obtain the line c_1d. This cuts AOB at $-5.6°$, and the stress implied at the spring root of the semi-rigid wing is proportional to 5.6—say, $5.6C$.

Actually, the aerodynamic moment varies with angular distortion according to the line CD, which cuts AOB at $6.7°$. So the stress at the root is $6.7C$. In this case, though a considerable underestimate is made by using the rigid wing assumption, the wing is still able to meet the loads on it without damage as permanent set does not occur until a stress of $8C$ is reached.

Next let us consider what happens at 450 f.p.s. Rigid wing aerodynamic calculations would, as shown by the point of intersection of c_2e with AOB, indicate a stress of $7.2C$, which implies no failure or permanent distortion. Taking account of the effect of distortion or aerodynamic load, however, the line CE shows that the stress is $9C$ and though complete failure does not occur, permanent distortion has been produced.

For a speed of 482 f.p.s. the rigid wing aerodynamic moment indicates, by the cutting of the lines c_3f and AOB to the left of PQ_1Q_2 that a small permanent set might occur if so high a speed were reached. But the line CF is tangential to AOB, and though the tangent is at only $-12\frac{1}{2}°$ while the failing stress is associated with $14°$, yet nevertheless failure occurs. Emphasising this point, it will be appreciated that at, say, 481 f.p.s. the two moment lines would cut, implying merely permanent set but not failure. At 483 f.p.s. and higher speeds (*cf.* the 500 f.p.s. line in the diagram) however the lines would not cut at all, implying that equilibrium of elastic and aerodynamic moments was impossible, or in other words that attainment of the speed meant failure. 482 f.p.s. is consequently the critical divergence speed, and illustrates the point that a stress

less than the failing stress of the structural material may be associated with collapse of the wing structure. The line marked CH in the figure is parallel to Q_1O and corresponds to a speed of 960 f.p.s.; this is the divergence speed obtained from the discussion of the stability of small motions of the wing at low incidences and is the speed at which critical divergence would occur if through all angles the wing twist varied directly as the applied moment. It is of academic

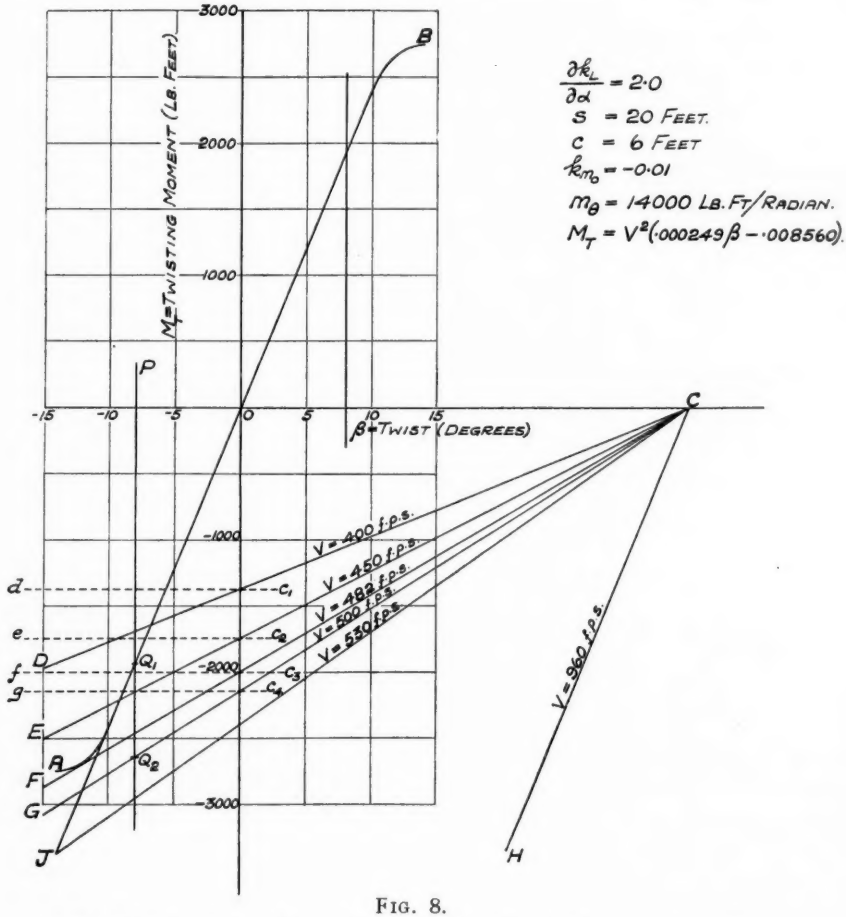


FIG. 8.

Equilibrium of aerodynamic and elastic torsional moments on the semi-rigid wing of an aeroplane in a vertical dive.

interest only. A speed obtained in the diagram equally easily is that corresponding to the assumption that the wing distorts linearly right up to the point of failure. This is given by the line CJ which corresponds to a speed of 530 f.p.s.

In this illustration, the semi-rigid wing has been given characteristics which make it comparable with the wings of actual aeroplanes which, however, do not

travel quite so fast as 482 f.p.s. With the attainment of higher and higher standards of speed I suggest that the type of failure to which I have drawn attention is far from unlikely; it may have already occurred. Its avoidance lies in the use of high torsional stiffness. If in the semi-rigid wing I have used for illustration the torsional stiffness were increased in the ratio of $PQ_2/PQ_1 = 2630/1952 = 1.35$, permanent set could not have occurred at less than 500 f.p.s. and failure would have been deferred to still higher speeds.

§5. *Wing Stiffness and Aeroplane Stability*

Discussion of the stability of an aeroplane is usually based on the assumption that the aeroplane is rigid. It is possible, however, to investigate the effect of wing elasticity on stability, and in this connection the problem of longitudinal stability has received some attention.[11]

The essential derivatives can be written in forms involving the wing elasticity, and the general effect of elasticity can be deduced. The conclusions are that wing elasticity will usually have a detrimental effect on longitudinal stability which will tend to be more or less dangerous according as the speed of the aeroplane is close to or remote from the instability speed (*cf.* Fig. 8) for its wings. To eliminate this effect entirely the ideal course would be to adopt a wing section with a constant C.P. position and arrange that the C.P. locus is such that aerodynamic loads produce no torsional distortion of the wings. The practical procedure would be to make k_{mo} for the wing section as small as other considerations permit, and the torsional stiffness of the wings as great as possible.

No quantitative information of a general nature is available, but calculations for a particular aeroplane are not difficult, especially if its wings can be imagined replaced by equivalent semi-rigid wings. To give an idea of the order of the elasticity effect, it may be noted that for a particular aeroplane of normal characteristics, taking into account the wing torsional stiffness was approximately equivalent to assuming the wings rigid and moving the centre of gravity aft .5in. at 170 f.p.s. or 1.4in. at 220 f.p.s.

§6. *Notes on the Provision and Calculation of Wing Stiffness*

It appears from §§2, 3, 4 and 5 that when designing a wing, in addition to determining the strength by the conventional procedures, it is necessary to arrange that

(i) The flexural stiffness is adequate on flutter considerations,

(ii) The torsional stiffness is sufficiently high to make unlikely flutter, loss of lateral control, and divergence due to torsional distortion, and have no appreciable detrimental effect on longitudinal stability.

It becomes essential therefore to know how to calculate the stiffnesses of wings.

The estimation of flexural stiffness presents no difficulty, as it is dependent only on the moment of inertia of the cross-section of the wing. Moreover, with mass-balanced ailerons fitted, the provision of the amount of flexural stiffness indicated in Fig. 2 is not difficult. I do not propose, therefore, to consider the question of flexural stiffness any further.

Means of providing sufficient wing torsional stiffness and of calculating wing torsional stiffness are, however, problems with which designers, particularly those interested in monoplanes, are now very much concerned. Some are, in their search for torsionally stiff wings, employing structures of unconventional form, each with its own problems of strength and stiffness calculation. Others still adhere to the conventional two-spar construction, the possibilities of which, even when unassisted by three-ply or metal covering, are by no means exhausted.

There is indeed much to be learnt from the behaviour of the two-spar cantilever wing. For a long time its ability in resisting torsional distortion was

seriously underestimated. Calculations of its torsional stiffness were frequently made on the assumption that its resistance to torsion resided only in the bending stiffnesses of the spars.

If for simplicity, we consider two spars with a single rigid rib, as in Fig. 9, it is easily seen that if differential bending of the spars occurs, torsional distortion of each is a necessary concomitant. Consequently if in a wing the ribs are stiff

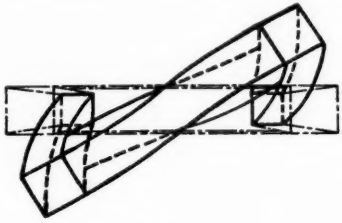


FIG. 9.

Two encastré spars connected by a rib rigid against flexure but weak against torsion.

in their own planes and robustly connected to the spars, we shall expect the latter to resist torsional wing distortion by twisting as well as bending. As an example we may consider the cantilever wing structure shown in Fig. 11. Under a uniformly distributed torque, if the torsional stiffness due to differential bending of the spars is alone considered, the angular distortions along the span appear to be as shown in Fig. 12, Curve 1. If, however, the ability of the stiff ribs to force the spars to twist to the same angle as the wing at every section is admitted,[12] the angular distortion is as in Curve 2. The proportion of the total stiffness due to the spars twisting is so great as to make the provision of stiff ribs, firmly connected to the spars, a primary design consideration.

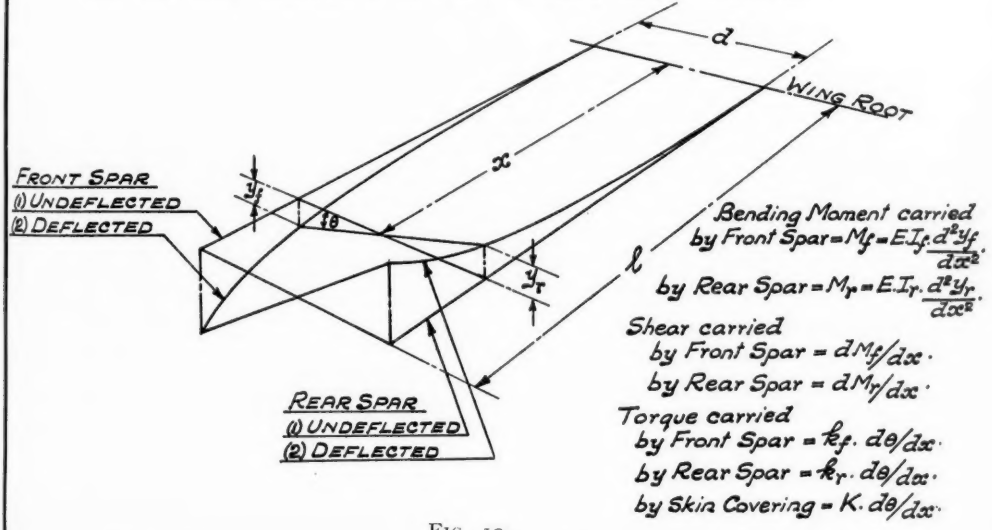


FIG. 10.

Wing with two encastré spars connected by ribs stiff in their own planes. Definitions of quantities referred to in Figs. 11, 17, 18.

In the calculations on which Fig. 12 was based, the ribs were supposed rigid and rigidly connected to the spars. It has been shown theoretically,[13] and confirmed by experiment on an actual wing[14] that the actual stiffness in its own plane of an ordinary rib is such that the assumption of its complete rigidity involves inappreciable error so long as it is firmly connected to the spars.

Theoretical examination of the problem of the torsional stiffness of two-spar wings indicates that the tip rib plays a much more important part than any of the others in introducing the spar torsional stiffnesses. It is therefore of interest to notice how the wing of Fig. 11 would distort if all the ribs except the end one were removed. The result is shown in Fig. 12, and has been confirmed by

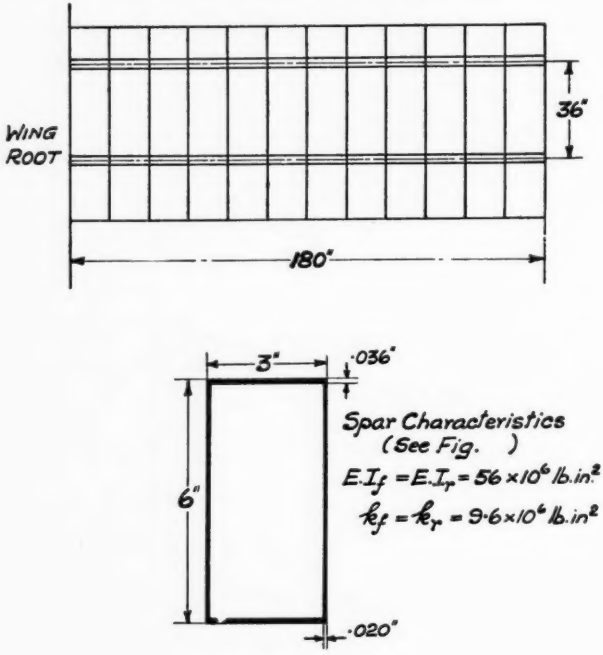


FIG. 11.

Cantilever wing with two parallel steel spars of equal and constant section connected by ribs stiff in their own planes.

experiment.[14] In designing for stiffness, therefore, there is justification for making the end rib especially robust and especially well connected to the spars. If in doing this a box-rib is employed, a further accretion to torsional stiffness occurs. This is illustrated by Fig. 13 in which the rib is supposed to have no flexural stiffness but to be undeformable about its own axis. The behaviour of spars connected by a rib rigid in torsion as well as in flexure is illustrated in Fig. 14, and if such a rib were introduced at the tip of the wing of Fig. 11, the stiffness under uniformly distributed torque as measured at the tip would be increased by 17 per cent.

It might be thought that the effectiveness of the flexurally stiff end rib became less if the spar cross-sections diminished rapidly towards the wing tip. This does not, however, appear to be the case. Exact mathematical solutions

giving the stiffnesses of wings of varying degrees of taper of cross-section can be obtained, and in all cases so far considered the stiffness obtained on the assumption that only the end rib is present is a good approximation.

Now the calculation of the torsional stiffness of a wing of arbitrarily varying cross-section (unlike the case of the wing of constant cross-section) when allowing for the effects of all the ribs is a laborious process; even in the cases where the law of variation of cross-section permits a mathematical solution, the numerical

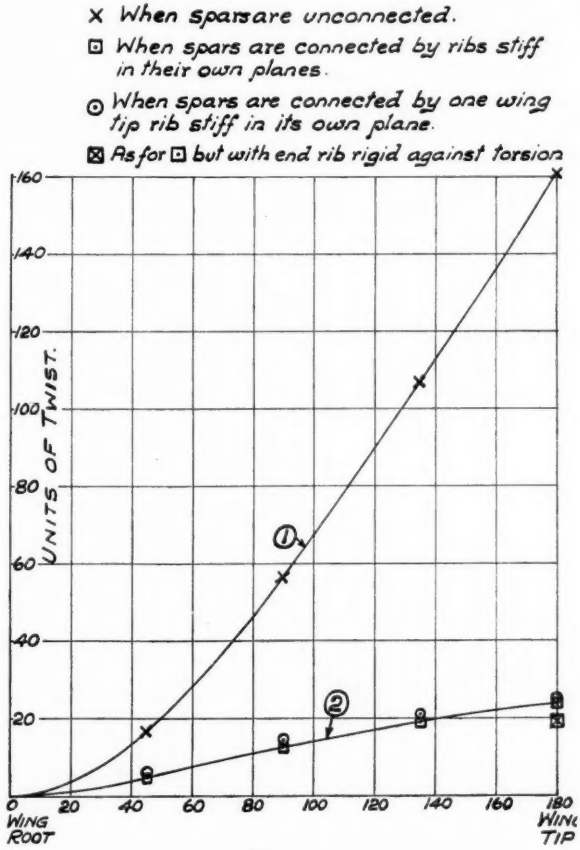


FIG. 12.

Angular distortions of wing of Fig. 11 *under uniformly distributed torque.*

work is arduous. But in all cases the calculation of the case when only the end rib is present is easy. If then the single end rib assumption gives always a good approximation to the correct answer, the practical procedure is clear, and it is worth indicating how the approximate calculation is made.

Suppose (as is necessary in calculating m_θ for flutter stiffness criteria) that the torsional stiffness under a torque applied at the wing tip of a cantilever wing is required. If a torque is applied at the wing tip, we can suppose it equal to

$t_b + {}_f t_t + {}_r t_t$ where t_b is the torque resisted by differential bending and ${}_f t_t$ and ${}_r t_t$ are the torques resisted by the twisting of the spars. Due to t_b, the front spar will deflect (downward) as a cantilever under a load t_b/d at the tip, and the rear spar will deflect (upward) under t_b/d at the tip. Thus the angular twist of the wing at the tip in terms of t_b will be known. The total twists of the front spar in terms of ${}_f t_t$ and of the rear spar in terms of ${}_r t_t$ will be easily calculable. These three twists must all be equal, so that the ratios $t_b : {}_f t_t : {}_r t_t$ follow. For a given torque T, $t_b + {}_f t_t + {}_r t_t = T$ so that t_b, ${}_f t_t$, ${}_r t_t$ are determinable. The twist for a torque T is then obtained from any one of the three expressions for twist.

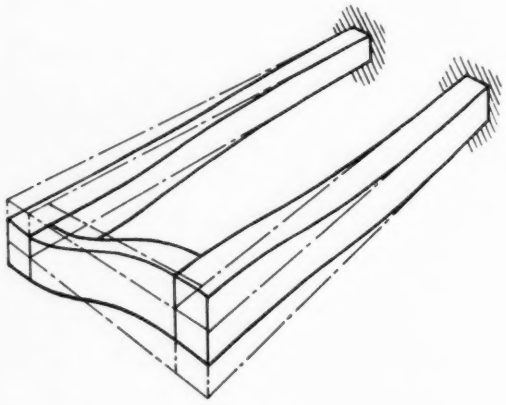


FIG. 13.

Two encastré spars connected by a rib rigid against torsion but weak against flexure.

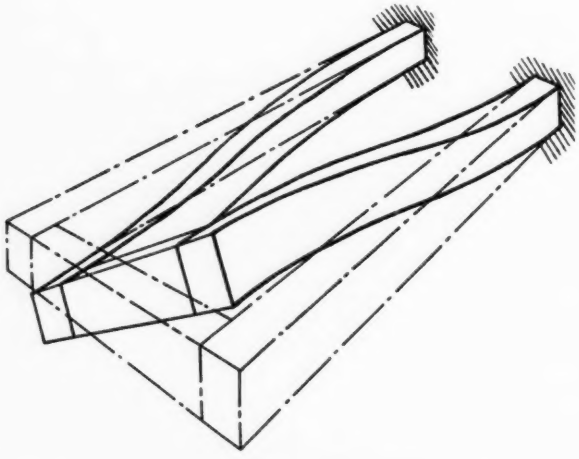


FIG. 14.

Two encastré spars connected by a rib rigid against both flexure and torsion.

§7. *Effect of Torsional Stiffness on Strength Calculation*

The deliberate provision of torsional stiffness in a wing by other means than spar differential bending necessarily involves departure from what are generally termed standard methods of stressing if accurate strength estimates are required.

In the ordinary two-spar wing, it is customary to assume that the applied loads produce only bending and shearing stresses in the spars. These are obtained by apportioning the load between the spars, and " stressing " them individually. The procedure is correct

(i) If the spars have no appreciable torsional stiffness (if, for example, they are *I* beams),

(ii) If the ribs are flexibly connected to the spars.

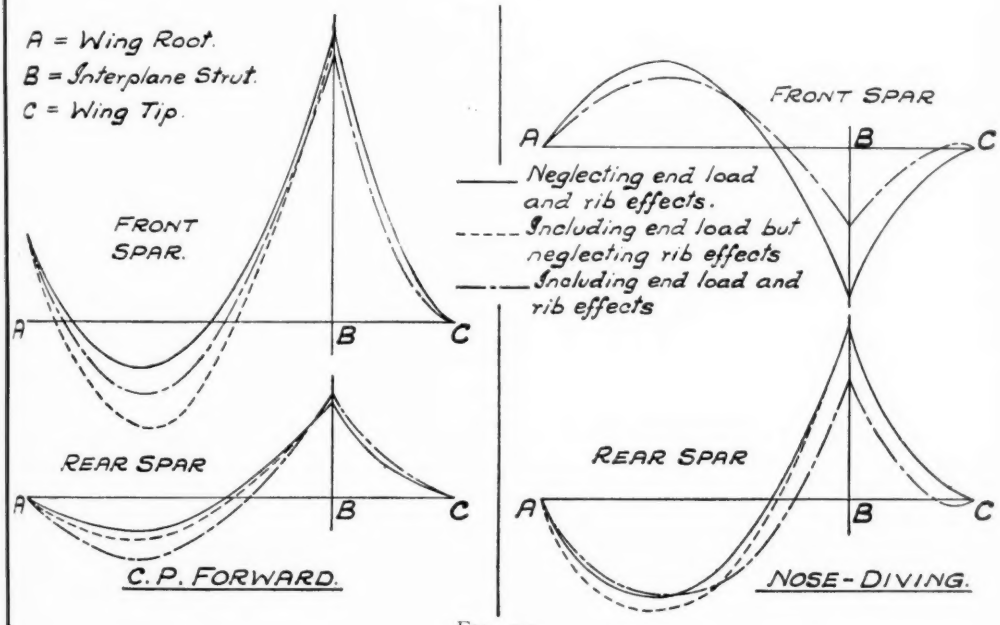


FIG. 15.

Bending moment diagrams for the top wing of a typical single bay biplane.

If, however, the spars are of box-section and are connected by stiff ribs firmly attached to them, the fact, already noticed, that the spars must twist as the wing as a whole twists, means that such part of the applied load system as is causing twisting is in part resisted by torsional stresses in the spars.[15]

In Fig. 15 the dotted lines show the front and rear spar bending moments as normally calculated for C.P.F. and N.D. on a typical biplane top wing with box spars. The full lines show the bending moments which would have resulted had the " Berry effect " been omitted from the calculations. The chain dotted lines show the spar bending moments, assuming the ribs to be rigid and rigidly connected to the spars. The indication from this particular example is that what may be termed the " rib effect " reduces the design bending moments by amounts comparable in magnitude with the Berry effect. At the same time torsional stresses are introduced in the spars, but it does not appear in this

particular example that their influence on the principal stresses in the spars is important.[15]

The effect noticed is an important one, for, as more and more inherent torsional stiffness is employed, the bigger will the effect be. In approximate terminology, in a wing with box spars, the maximum spar bending moments will decrease the more the spar webs are bulged outwards until, when the bulging is so great as to coincide with the wing profile, giving a conception of the skin-covered two-spar wing, due account of the decrease cannot be ignored in economical design.

This is universally recognised, and the idea usually underlying the design of a skin-covered wing is that the spars shall resist the bending actions and the skin the twisting actions. The interpretation in calculation of this idea however varies, and, in the absence of any standard procedure, I propose to discuss some aspects of the problem which may be of use.

Fig. 16 represents a two-spar wing which may be supposed to have high inherent torsional stiffness in virtue of either the cross-sections of its spars or a skin covering. The diagram shows the locus of C.P. position, along which some distributed loading w per unit run of span is applied. Now there is some line which we may call the " flexural line " such that if this particular loading distribution were applied along it purely flexural distortion of the wing would occur. This line is shown in Fig. 16 at a variable distance rd ahead of the rear spar. On the assumption that the skin, if any, though capable of resisting torsion, gives no assistance to the spars in bending (a reasonable assumption when corrugated metal or thin three-ply is used), this line, as shown in Appendix II, is given by

$$rw = Zw + 2\,(dZ/dx)\int_1^x w\,dx + (d^2Z/dx^2)\int_1^x\int_1^x w\,(dx)^2 \quad . \quad . \quad . \quad (7)$$

where, referring to Fig. 16, and calling the arbitrarily varying moments of inertia of the front and rear spars I_f and I_r respectively,

$$Z = (I_f \cos^3 \alpha_f)/(I_r \cos^3 \alpha_r + I_f \cos^3 \alpha_f) \quad . \quad . \quad . \quad (7a)$$

Then the original load distributed along the C.P. locus can be represented by the same load similarly distributed along the flexural line together with a system of varying distributed torque obtained by multiplying w at each point by

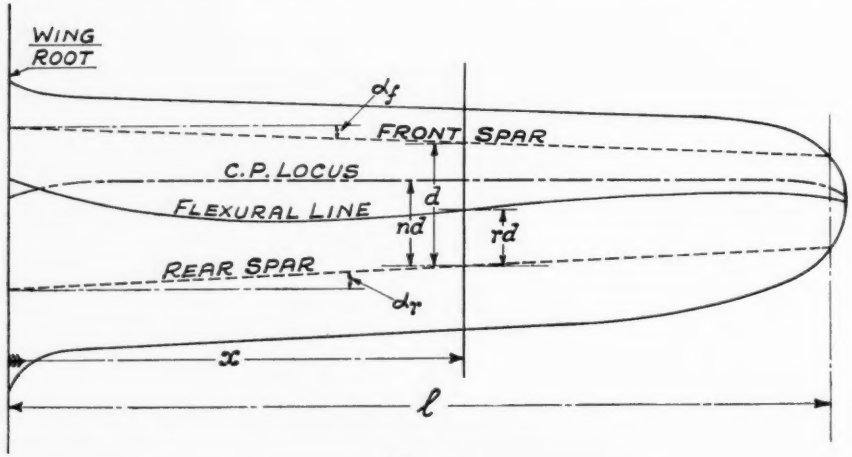


FIG. 16.
Diagram for definition of flexural line.

the distance there between these two lines. Referring to Fig. 16, if w is in the direction of lift, the distributed torque per unit run tending to cause the leading edge of the wing to rise is $d\ (nw - rw)$.

While the loading along the flexural line may now be regarded as producing only spar bending stresses, the torque system cannot be regarded as producing only skin and spar torsional stresses. It will produce spar bending stresses as well as torsion stresses, and the determination of these will need to be by methods analogous to those given for stiffness calculation in R. & M. 1436.[12]

As an example, for a wing in which the skin and spar constants are defined as in Fig. 17, the partition of the resistance to uniformly applied torque between the skin in torsion and the spars in bending is shown in Fig. 18.

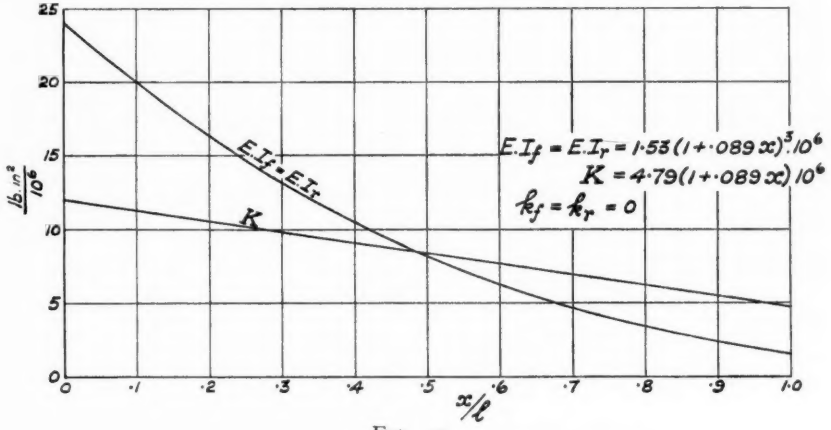


FIG. 17.
Spar and skin characteristics for a typical ply-covered wing (see Fig. 10).

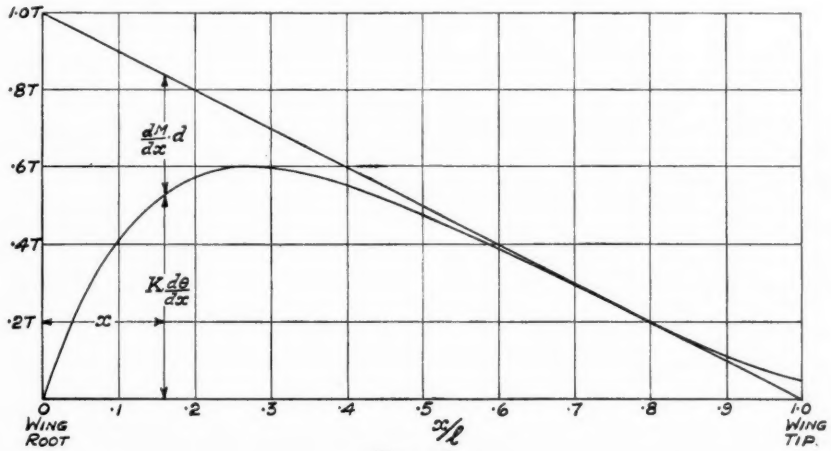


FIG. 18.
Partition of uniformly distributed torque T between skin and spars of the ply covered wing defined in Fig. 17 (see Fig. 10).

§8. *Acknowledgments*

In thanking the Air Ministry for permitting me to give this lecture, I have to point out that I am solely responsible for its contents. I wish to acknowledge my indebtedness to Mr. Pugsley and Mr. Williams and those others of my colleagues with whom I have been associated in the work I have described.

Appendix I.

Definition of Reversal Coefficient

Supposing a particular wing fixed to a fuselage immobile in roll, pitch, and yaw, to be rigid, the rolling moment produced by a small aileron displacement ξ may be expressed as

$$L(\xi) = k_\xi \rho V^2 s^2 c \xi,$$

where k_ξ is a constant non-dimensional coefficient.

If now the wing is supposed semi-rigid, and if it is assumed that the aileron angle relative to the wing is unaffected by wing twisting, the rolling moment due to distortion of the wing alone may be written

$$L(\theta) = k_\theta \rho V^2 s^2 c \theta,$$

where k_θ is a constant non-dimensional coefficient and θ is the wing twist at a chosen reference section.

If on the semi-rigid wing the aileron angle ξ and the twist θ occur together, the total rolling moment is

$$L(\xi) + L(\theta).$$

The forces producing this rolling moment on the semi-rigid wing can be represented by lift forces applied in such a way as to cause pure flexure together with a distributed torque of T per unit run of the span. This distributed torque is represented at the reference section by a torque equal to

$$\int_0^s T(\theta'/\theta)\, dx$$

where θ' is the twist at any section distant x from the wing root. If this reference section torque is divided into two parts $M(\xi)$ and $M(\theta)$ corresponding to $L(\xi)$ and $L(\theta)$, we may write

$$M(\xi) = c_\xi \rho V^2 s c^2 \xi,$$
$$M(\theta) = c_\theta \rho V^2 s c^2 \theta,$$

to define the constant non-dimensional coefficients c_ξ and c_θ.

Then the reversal coefficient is given by[6]

$$K = \sqrt{\{ -k_\xi / (k_\theta c_\xi - k_\xi c_\theta) \}}$$

It can be shown that for a semi-rigid wing and aileron of ordinary proportions[16] this reduces to

$$K = \sqrt{(-k_\xi / b_2 k_\theta)}$$

where b_2 is defined by the linear relation

$$c_\xi = c_2 k_\xi + b_2.$$

It can be demonstrated[16] that for the derivation of K, the coefficients k_ξ, k_θ, and b_2 may be estimated on the basis of " strip theory " without introducing appreciable error.

Appendix II.

The Flexural Line for a Wing

If a two-spar cantilever wing carries a varying distributed loading of w per unit run, it is required to determine how this loading must be apportioned between the two spars if no twisting of the wing is to occur.

Suppose that pure flexure of the wing occurs if the loading per unit run of the

x-axis on the front and rear spars respectively is wr and $w(1-r)$ where r is a variable along the span. Then referring to Fig. 19,

$$EI_f (d^2y_f/dx^2_f) = \int_1^{x_f}\int_1^{x_f} wr \cos \alpha_f (dx_f)^2 \quad . \quad . \quad . \quad (1a)$$

$$EI_r (d^2y_r/dx^2_r) = \int_1^{x_r}\int_1^{x_r} w (1-r) \cos \alpha_r (dx_r)^2 \quad . \quad . \quad (1b)$$

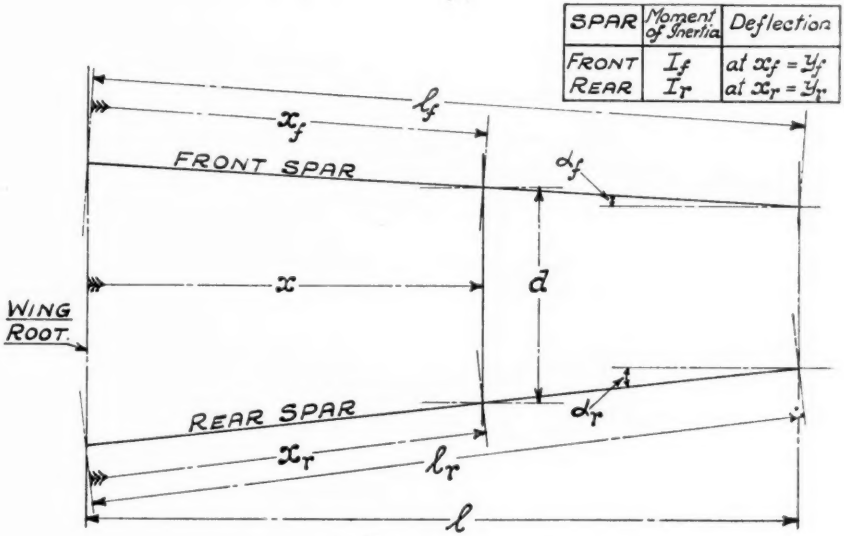


FIG. 19.

Diagram defining terms used in Appendix II.

As $x = x_f \cos \alpha_f$ (1a) may be written

$$EI_f (d^2y_f/dx^2) \cos^2 \alpha_f = \int_1^x\int_1^x wr \cdot \cos \alpha_f \{ (dx)^2/\cos^2 \alpha_f \}$$

$$i.e., \quad d^2y_f/dx^2 = (1/EI_f)(1/\cos^3 \alpha_f) \int_1^x\int_1^x wr (dx)^2 \quad . \quad . \quad . \quad . \quad (2a)$$

Similarly, as $x = x_r \cos \alpha_r$, from (1b),

$$d^2y_r/dx^2 = (1/EI_r)(1/\cos^3 \alpha_r) \int_1^x\int_1^x w (1-r) (dx)^2 \quad . \quad . \quad . \quad (2b)$$

If the wing is not to twist, then

$$d^2y_f/dx^2 = d^2y_r/dx^2$$

for all values of x. That is, equating the right hand sides of (2a) and (2b), and rearranging

$$\int_1^x\int_1^x wr (dx)^2 = (I_f \cos^3 \alpha_f / I_r \cos^3 \alpha_r) \left\{ \int_1^x\int_1^x w (dx)^2 - \int_1^x\int_1^x wr (dx)^2 \right\} \quad . \quad (3)$$

If for shortness we put

$$Z = (I_f \cos^3 \alpha_f)/(I_r \cos^3 \alpha_r + I_f \cos^3 \alpha_f)$$

(3) becomes

$$\int_1^x\int_1^x wr \cdot (dx)^2 = Z \int_1^x\int_1^x w (dx)^2 \quad . \quad . \quad . \quad . \quad (4)$$

Doubly differentiating (4)

$$wr = Zw + 2 (dZ/dx) \int_1^x w dx + (d^2Z/dx^2) \int_1^x\int_1^x w (dx)^2 \quad . \quad . \quad . \quad . \quad (5)$$

This defines the flexural line as being at a varying distance rd, measured normal to the x-axis, ahead of the rear spar. It follows that if in a particular case the loading w is lift applied to the wing along a C.P. locus distant nd ahead of the rear spar, it can be represented by a loading w causing pure flexure of the wing together with a varying distributed torque $wd\,(n-r)$ tending to depress the rear spar.

APPENDIX III.

List of References

Ref. No.	Title.	Author.	Official Ref.
1.	The flutter of aeroplane wings.	R. A. Frazer and W. J. Duncan.	R. & M. 1155.
2.	The flutter of monoplanes, biplanes and tail units.	R. A. Frazer and W. J. Duncan.	R. & M. 1255.
3.	A statistical method of investigating the relations between the elastic stiffnesses of aeroplane wings and wing-aileron flutter.	H. Roxbee Cox.	R. & M. 1505.
4.	The influence of wing density upon the flutter of aeroplane wings.	A. G. Pugsley.	R. & M. 1497.
5.	The flexural-torsional flutter characteristics of a simple cantilever wing representative of current practice.	D. Williams.	R.A.E. Report No. A.D. 3034 (unpublished)
6.	The calculation by successive approximation of the critical reversal speed for an elastic wing.	A. G. Pugsley and G. R. Brooke.	R. & M. 1508.
7.	Theory of loss of lateral control due to wing twisting.	H. Roxbee Cox and A. G. Pugsley.	R. & M. 1506.
8.	Experiments on the reversal of aileron control due to wing twist.	W. J. Duncan and G. A. McMillan.	R. & M. 1499.
9.	On the calculation of the critical reversal speeds of wings.	D. M. Hirst.	R. & M. 1568.
10.	The stability of the static equilibrium of the elastic and aerodynamic actions on a wing.	H. Roxbee Cox and A. G. Pugsley.	R. & M. 1509.
11.	Influence of wing elasticity upon the longitudinal stability of an aeroplane.	A. G. Pugsley.	R. & M. 1548.
12.	Cases of purely torsional loading in stripped aeroplane wings.	H. Roxbee Cox.	R. & M. 1436.
13.	On the effect of stiff ribs on the torsional stiffness of aeroplane wings.	H. Roxbee Cox and D. Williams.	R. & M. 1536.
14.	Experiments on the distortion of a stripped two-spar metal wing under torsional loading.	D. Williams and H. F. Vessey	R. & M. 1571.
15.	The effect of the ribs on the stresses in the spars of a two-spar wing subjected to the most general type of loading.	D. Williams and H. Roxbee Cox.	R. & M. 1538.
16.	The aerodynamic characteristics of a semi-rigid wing relevant to the problem of loss of lateral control due to wing twisting.	A. G. Pugsley.	R. & M. 1490.

Discussion

The Chairman: The work described followed that of Fraser and Duncan, at the National Physical Laboratory, on the question of flutter. Methods discussed in the paper had been applied within the limits of our experience, and such application had certainly given confidence in their use.

Dr. W. J. Duncan, D.Sc., A.M.I.Mech.E. (National Physical Laboratory): The paper summarised many distinct though cognate investigations and it merited and would repay close study. The salient fact which merged from the various discussions given in the paper was the great value of high torsional wing stiffness. For example, this raised the critical speeds for wing flutter and for reversal of aileron control. It was worth emphasising that the features of design which were good from the points of view of flutter and reversal of control were not antagonistic. For example, the best position of the flexural axis of the wing from the flutter point of view was rather far forward, say at 0.25 to 0.30 of the chord from the leading edge. But, as Dr. Cox and Mr. Pugsley had shown, this forward position of the flexural axis did not result in a low critical reversal speed, as might appear probable on a casual examination of the problem.

The fixing of numerical values for the wing stiffnesses which would be sufficient to ensure immunity from flutter within the range of possible flight speeds was a matter of great difficulty. In order to calculate the critical flutter speed of a cantilever wing with aileron the values of 26 coefficients were required. Of these, six were inertias, four were elastic constants, and sixteen were aerodynamical derivatives. Even the inertias and stiffnesses were not very readily obtained, and many of the derivatives could at present only be deduced from rather difficult experiments on models. Hence it was not practicable to include the theoretical prediction of critical flutter speeds in the routine procedure for the determination of airworthiness, and the statistical method used by Dr. Roxbee Cox seemed to be the only alternative. Dr. Duncan considered this method to be of real value, but naturally it could never yield a precise answer. It was, therefore, of great importance that the proved methods of flutter prevention, such as mass balance of the ailerons, should be adopted as a matter of course. The only safe exceptions would be cases where Dr. Cox's criteria showed the elastic stiffnesses to have really large surplus margins.

Before passing from the question of wing flutter, he mentioned that in the course of the experiments on reversal of aileron control, described in item 8 in the list of references at the end of the paper, Mr. McMillan and himself had found that the cantilever wing, being tested, developed flexural-torsional flutter below the speed at which the aileron control reversed. In order to reach the reversal speed they found it necessary to mass balance the wing by loading it near the leading edge. Hence it must not be lightly assumed that flexural-torsional flutter—which Dr. Roxbee Cox called pure wing flutter—would never occur in practice.

In connection with reversal of control, it was of some interest to note that if the wing had zero torsional stiffness, the effect of the aileron would always be reversed. This was the actual state of affairs in a servo-controlled elevator or rudder, where the flap played the part of the aileron, and the force or moment produced by the complete control surface was of opposite sign to that which would be produced by the flap alone.

Figs. 5 and 6 showed that there was a marked reduction in the torsional wing stiffness required for avoidance of reversal of control when the wing was highly tapered. He suggested, however, that this gave a rather false impression —at any rate where two-spar wings were concerned—since it became much more difficult to secure a *given* torsional stiffness when the wing was highly tapered.

The part of the paper dealing with the influence of rib design on torsional wing stiffness was of great value, but he did not feel competent to discuss it in detail. He asked, however, whether he was right in supposing that high

torsional stiffness of the ribs was the chief desideratum. It appeared probable that this would be true when the number of torsionally stiff ribs was large, for these would tend to equalise the slopes of the front and rear spars, and therefore also their deflections.

Dr. LACHMANN, F.R.Ae.S.: Dr. Roxbee Cox had given a good deal of valuable advice to the designers of monoplanes. That advice was based mainly on his own work and that of other research workers in this country, therefore Dr. Lachmann drew attention to the work which had been done in other countries on the same problems, some of the results of which might well fill some still existing gaps in present research in this country.

With regard to the required amount of wing stiffness for the prevention of wing flutter, research work in this country had dealt mainly with the question of aileron flutter; the problem of pure wing flutter had received less attention. Although Dr. Roxbee Cox had given some interesting statistical information of flexural and torsional stiffness criteria for a certain number of monoplanes which he had analysed, which information might give valuable hints to the designer of monoplanes of ordinary construction similar to those analysed, Dr. Lachmann suggested that a more exact criterion was desirable. In this connection he drew attention to the work done by the D.V.L. in Germany, especially by Dr. Küssner, who had published a report on the oscillation of aeroplane wings in the D.V.L. Year Book of 1929, dealing with the exact theory of oscillations of aeroplane wings on the basis of the Prandtl-Birnbaum conception of a flapping wing in non-stationary flow. Although Dr. Küssner's investigations had shown the actual solution was too complicated for the designer's use, he had arrived at relatively simple approximations which enabled one to predict with fair accuracy the critical velocity where pure wing flutter would occur, provided the frequencies for flexural and torsional oscillations and the elastic characteristics of the wing area were known.

It is noteworthy that an approximate formula for the critical flutter speed suggested by Küssner resembles very closely the formula derived by Dr. Cox for aileron reversal speed.

Küssner's formula is

$$v_k = k \sqrt{(GI_D/A^2\rho)}$$

where $k = 4.25 - 5.95$ (depending on wing construction)
GI_D = Torque stiffness at wing root.
A = Area.
ρ = Density.

The frequencies of flexural and torsional oscillations were determined in Germany usually by test, where the whole aeroplane was slung in bungees and the oscillations were caused by an electromotor fitted with an unbalance. The smallest frequency in the neighbourhood of which growing wing oscillations at the lowest critical velocity might be expected was characterised by equal torsional and flexural amplitudes of the neutral axis. After the frequency had thus been determined, an estimate of the critical velocity could be made, introducing the conception of reduced frequency, which was

$$w = c_m n/2v, \text{ where } c_m = \text{mean chord},$$
$$n = \text{frequency},$$
$$v = \text{velocity}.$$

By analysing experimental and statistical data it was found that the value for this reduced frequency for wing with mass balanced ailerons was of the order of .86, and the critical speed therefore became $v = nc_m/1.72$. It was fairly easy, therefore, by the use of this simple formula, to predict the critical speed for a new construction if the critical frequency were known. On the other hand, if, for a design, critical speed and wing chord were given, the required minimum frequency of the wings could be estimated. As wing torsion was the most

important degree of freedom, one could then determine the torsional stiffness required to give the required frequency for a pure torsional oscillation.

Admittedly torsional rigidity of the wing was one of the most important requirements for the prevention of wing flutter, but it was not the only one. Another very important criterion was the position of the inertia axis relatively to the axis of independence. It followed from the theory that the critical speed went to higher values the more the inertia axis moved towards the axis of independence. The single-spar wing here offered great advantages as the single-spar construction was able to bring the c.g. of the wing farther forward than on a two-spar construction. Consequently, single-spar wings of the same torsional rigidity as two-spar wings were safer in regard to wing flutter than two-spar constructions. In the paper by Dr. Küssner, mentioned before, critical flutter speeds were calculated for a multi-spar wing of the Junkers type, and a single-spar wing of the Messerschmitt type, and it followed from this investigation that under equal conditions, *i.e.*, equal wing area and equal torsional stiffness at the wing root, critical flutter speed of the single-spar wing would be about 40 per cent. above the flutter speed of the multi-spar wing.

A valuable new criterion was introduced by Dr. Roxbee Cox, namely, the critical reversal speed. From an example which Dr. Lachmann had investigated, it would appear that this critical reversal speed was about of the same order as the critical speed determined by the German methods. In a particular case the critical speed for aileron reversal was 430 m.p.h., the nose dive speed 350 m.p.h., and the critical speed for wing flutter 440 m.p.h. This example indicated that the aileron reversal speed was quite a sufficient stiffness criterion in this particular case; however, it remained to be seen to what extent this result could be generalised. The criterion for aileron reversal speed was certainly a very essential and necessary requirement because one could imagine a wing which by its particular position of inertia axis would require a relatively small amount of torsional stiffness, insufficient from the point of view of aileron reversal speed.

The methods which Dr. Roxbee Cox proposed for obtaining and calculating sufficient wing stiffness referred mainly to the two-spar construction. Dr. Lachmann believed, however, that the two-spar construction, even when improved by flexural and torsionally stiff end ribs, could never compete with the skin-covered construction in regard to torsional stiffness at low structure weight. Methods of calculating the effect of the end ribs described by Dr. Roxbee Cox had been known for a good many years and very extensive literature existed on this subject. In Germany the problem had been mainly investigated by Dr. Thalau of the D.V.L., whose first publication dated back to 1925, but there were also contributions by von Karman, Koning, Koch and Biezeno of Holland, Gabrieli of Italy, etc.

In regard to the calculation of wings consisting of two spars and skin covering, he believed it was simpler to treat this case by means of Bredt's theorem than by the more complicated method of a compound effect caused by an infinite number of ribs. The method gave very satisfactory results, except at those points where the deformation of the cross sections of the wing was prevented by stiff attachment to the fuselage or struts, etc. At this point additional stresses would occur.

Mr. H. J. Pollard, A.F.R.Ae.S.: Referring to Fig. 16, and the statement that " if w is in the direction of lift, the distributed torque per unit run tending to cause the leading edge of the wing to fall is $d(nw - rw)$," he suggested that the word " fall " should be " rise."

The diagram in Fig. 18 was most instructive, and it seemed encouraging from the point of view that making holes in a wing root for the reception, for example of tanks, would not interfere too much with the torsional stiffness of the wing.

Professor L. BAIRSTOW, F.R.Ae.S.: Practically all the problems dealt with in the paper had arisen out of difficulties in flight, and were chiefly concerned with the stiffness or flexibility of wings; there were other troubles connected with the stiffness of the fuselage of an aeroplane or the hull of a flying boat, and one recognised how very difficult it was to say, in the course of design, or even when the design was completed, whether a given structure would or would not give trouble owing to its flexibility. Perhaps he saw one aspect with undue prominence, but he wished to draw attention to the fact that new problems were constantly arising for which there was very little information on which to begin an investigation. The torsional stiffness of wings, for instance, was rarely known, and the first step in an investigation was to measure it; the same remarks apply to the moments of inertia of parts, etc., and it all entailed considerable delay on the research side. Therefore, he asked quite seriously whether the design side was not a little too far behind research. During accident investigations fifteen years ago, the position of the centre of gravity was usually unknown with the requisite precision. Nowadays, of course, every designer knew the position of the centre of gravity of his aeroplane, and the permissible limits were laid down in the airworthiness certificate. It seemed that in regard to the flexibility problems, we were now in the position reached in regard to the centre of gravity fifteen years ago, and Professor Bairstow appealed to designers to measure more of the things which were important and not regard this part of progress as the domain of research. To indicate the present state he asked Dr. Roxbee Cox, in connection with the preparation of the diagrams in the paper, in how many cases information of the rigidity of the wings considered was given to him and in how many cases it had to be measured or calculated at Farnborough.

It was agreed that the calculations necessary for examining flutter in detail were extremely difficult; consequently, somebody—usually the Airworthiness Department of the Air Ministry—had to make rules. That was a very good thing, provided the rules were understood. There were certain rules for mass balancing to avoid flutter, but they all assumed a knowledge—roughly, at any rate—how the aeroplane was going to bend or twist. If the motion of the fuselage were mainly torsion there would be one calculation, whilst if the motion were mainly bending there would be another. One suspected that the theoretical work, which had been carried out with great care and at considerable expense, and which had been published, was not read sufficiently widely to enable the rules to be applied properly. In other words, a great deal too much was thrown upon organisations such as the Royal Aircraft Establishment and the Research Committee in regard to the safety of aircraft. He felt that the work there was to a large extent restricted unless designers co-operated fully in applying it. From that point of view he welcomed Dr. Roxbee Cox's paper; it showed that a Government Department was working hard on these problems, and he had little doubt that the rest would come in due course. The aim of his remarks was to urge some acceleration of the process.

Mr. SCOTT HALL, A.F.R.Ae.S.: He raised the question as to whether they were considering wing stiffness, or for that matter the stiffness of any part of an aircraft, with such care, because they were unable to cope in any other way with the fluctuating forces applied to it. In this connection he drew attention to the author's statement that the success of any structure designed to carry varying loads depended upon its qualities of strength and of *stiffness*, and to the special example given in the case of the stiff end rib to the wing. It might be interpreted, from all this work, that the only cure for the trouble was to make the structure extremely stiff. But, on the other hand, one could quote a number of successful structures which definitely were not stiff, amongst which were ships. He had in mind a particular sailing boat. This was admittedly an extreme case, and it might seem absurd to refer to it, but the point was that originally this particular boat was in a condition he would describe as " easy,"

i.e., its torsional and flexural stiffness were small, and one could see the whole hull twisting as it went through the water. When the owner had the hull stiffened, it had the result of making the boat leak—and certainly did not improve its performance. That led one to ask whether there were not better ways of dealing with this problem than merely stiffening the structure. In this same connection, Mr. Scott Hall stressed the absurdity to which one could reduce, in the limit, the case referred to in the paper of a very stiff rib at the end of a very flexible wing.

Turning to Figs. 2 and 3, where the author had given the wing flexural stiffness and the wing torsional stiffness flutter criteria for monoplanes falling into the group defined by envelope A in Fig. 1, it would appear that 5 out of 21 cases in Fig. 2 had fluttered, and 3 out of 11 cases in Fig. 3 had fluttered. These percentages seemed rather alarming, and he would like to know if his interpretation was correct.

Finally, he asked whether any aircraft with mass balanced ailerons had given trouble in respect of wing flutter. This had a bearing on the argument as to whether there were not better ways of dealing with flutter than by stiffening a wing.

Dr. A. P. Thurston, F.R.Ae.S.: He was responsible, for two years during the war, for safety in design. The problem of torsion was studied a good deal at that time; he had laid down standard methods of calculation, and had been successful in getting at least one machine of each new type tested at the Royal Aircraft Factory. He urged, therefore, that there must exist at the Royal Aircraft Establishment an enormous mass of valuable information in connection with the structural rigidity and strength of various parts; this information probably needed tabulation, but it would be of vast interest to the aircraft industry of this country if it were made available.

He agreed with Mr. Scott Hall that considerably greater strength could be obtained by allowing flexibility in the right direction; if it were possible for a spar to yield and so allow the stress to redistribute itself, ofttimes a machine would withstand when in the air considerably more stress than was indicated by calculation.

The strength of the main rib holding the two spars together was a factor which it was important to watch; he knew of quite a number of machines which had gone to pieces in the air because the main rib holding the two spars together was not sufficiently rigid to prevent the flexing of the front spar relative to the other portions of the structure. If the front spar were sufficiently braced, so that it was torsionally rigid relative to the other, the other portions could be made sufficiently flexible to relieve the rib load, so that the structure was much safer than was indicated by the calculations set forth in Dr. Roxbee Cox's paper.

Mr. K. T. Spencer (Royal Aircraft Establishment): The paper called attention to several ways in which an aeroplane might be either stronger or weaker than the usual routine calculations would indicate. It had always been appreciated that the ribs contributed towards a hidden margin of safety in that they transferred load from the more heavily to the less heavily loaded spar; but previous to Dr. Cox's investigations there was no quantitative measure of the amount by which, due to rib effect, an aeroplane might be stronger than appeared from the usual approximate calculations. Again, it had always been realised that wing distortion affected the magnitude and distribution of the applied load, but hitherto this had generally been neglected in strength calculations. Dr. Cox had now given a quantitative measure of the unsafe error that might be introduced by neglecting this redistribution of load on a distorted wing.

It was important to consider what effect, if any, this new knowledge should have upon airworthiness regulations. The current airworthiness regulations both here and abroad were adopted long before many of the modern refinements of aerodynamic load determination and strength calculation were thought of, and it would perhaps be more by luck than judgment if such regulations were found

to fit in reasonably well with the latest developments. The rib effect, *i.e.*, the strength contributed by the transference of load from one spar to the other, via the ribs, would be automatically allowed for in the airworthiness regulations of such countries as pinned their faith to mechanical tests rather than to strength calculations. As a result of recent amendments to British airworthiness requirements, this country came within this category. Countries which still attempted to standardise methods of calculation instead of accepting mechanical tests as the final proof of structural strength would, presumably, have some awkward problems in store for them on this score.

The redistribution of applied load due to wing distortion, however, was not, so far as he could discover, taken into account in the official airworthiness regulations of any country except France. The 1931 edition of the Bureau Veritas regulations contained the following (para. 271) :—

> " Deformations under the influence of the calculated dynamic stresses must be studied and closely restricted in a certain number of cases," one of which was " Deformations liable to produce a dangerous variation in the distribution of the loads."

It was perhaps odd that other countries had not yet had to take account of it, even to the extent of including some reference to the matter in their airworthiness regulations. One country, Germany, had certainly had failures in the air due to this very effect. In " The Flying Dutchman," by Anthony Fokker, there was an interesting account of a series of failures in the air which followed the strengthening of the rear spar. The trouble was finally traced to the changed type of wing distortion consequent upon the stiffened rear spar, this giving rise to a divergence of one of the types described in the lecture. So there was no doubt that wing distortion could be a very real danger. It was a subtle danger, too, because in the case of the Fokker aeroplane in question it was not until the wings were strengthened that this particular trouble was experienced. Thus, the author's contention that it was necessary to design to a standard of stiffness, as well as to a standard of strength, was fully justified. Incidentally, this did not mean that wings had necessarily to be stiffer, but that it should be verified that the stiffness was correctly disposed. This inevitably meant more work for the stresser at present, but there was a chance that in the future suitable stiffness criteria might be found to replace, not add to, some of the present strength criteria. This was very much to be desired, as the continual growth of the investigations necessary in the design of an aeroplane would, if not checked, ultimately become a serious obstacle to aeronautical progress.

Mr. F. RADCLIFFE, A.F.R.Ae.S. (Gloster Aircraft Co.) : He thanked the author for his able summary of the researches made into the subject of wing stiffness and for having presented it in its true perspective, so that those concerned with construction could apply the results of that research. It occurred to him, however, that as load factors had been framed on statistical data acquired over a considerable number of years, and thus only had any significance when one took into account the basis on which they were framed, that possibly serious results might obtain if advantage were taken of the means the paper afforded of reducing spar strengths (particularly in biplanes). It was always appreciated that there was a hidden reserve of strength which was due to the assistance one spar gave to the other. Thus it would seem necessary that care should be exercised if the designer decided to reduce this hidden reserve to any appreciable extent. He would be glad, therefore, to hear the views of Dr. Roxbee Cox on this particular point.

Fig. 15 of the paper was of particular interest in connection with this matter as it related to the effect of the help given by the rear spars to the front spars, and vice versa. He asked if what was indicated with regard to the " Berry effect " had been confirmed by actual tests on skeleton wings, or whether the results were obtained by calculation only.

He gathered that much of the data in the paper had been based on spars of the box type, similar to those used in Wapiti wings; and it would be interesting if an indication could be made of the assistance that could be derived if the dumb-bell type of spar were employed. It was appreciated, of course, that a test would actually be necessary if such had not already been done by the R.A.E. before definite figures could be assumed, but he thought that possibly this point had been considered by the lecturer in the course of his investigations.

Mr. G. CORNWALL, A.F.R.Ae.S.: He thought the information in the paper would lead ultimately to saving of weight. When it was known what degree of rigidity had to be provided in a wing structure, the designer would not need to provide extra high rigidity in order to be sure that he was on the safe side. It was shown that it was not necessary to provide so much rigidity if the mass balance of ailerons or other anti-flutter devices were adopted. Alternatively, it was shown that if the higher degree of wing rigidity was attained by virtue of a wing construction in which high rigidity was inherent, as in the case of a skin-covered wing, for instance, then mass balancing of ailerons or other anti-flutter devices might themselves no longer be necessary. One felt that designers of British aircraft had been compelled unnecessarily to adopt such anti-flutter devices without regard to other considerations of design, particularly that of stiffness. He knew of a monoplane, of about 10,000lbs. weight, in which the ailerons were compulsorily mass balanced, entailing a sacrifice of about 40lbs. of its disposable load, although that machine had done considerable service without showing a disposition to wing-aileron flutter, and it could now be demonstrated by Dr. Roxbee Cox's statistical methods that it was immune from flutter by virtue of the wing stiffness. It was to be hoped that this paper, by giving greater prominence to much of the work that had already been published, would lead to a fuller realisation that aileron mass balance and a high degree of wing rigidity were alternative safeguards against the same danger, *i.e.*, that of wing-aileron flutter. Wing rigidity had the added advantage of being a specific against aileron reversal, and what Dr. Roxbee Cox had called pure wing flutter. With this knowledge in their possession, perhaps those who legislated for aircraft design would relax from what appeared to be a somewhat uncompromising attitude on the question of wing rigidity and aileron mass balance.

Mr. F. F. CROCOMBE, A.F.R.Ae.S.: He suggested that the most important feature of the lecture was the outline of the method of estimating torsional stiffness criteria to preclude aileron reversal. This was useful if possible to calculate the torsional deflection of a wing beforehand. So far, such a course was rarely possible in practice, and it was no great consolation to the designer to be an accessory after the fact.

One could profit best from the methods outlined by the author if the particular wing construction used lent itself to the calculation of torsional deflections. In the general recommendations stated in the paper, there was a very definite case for a single-spar wing of considerable plan form taper, and of such construction that the actual torsional stiffness could be controlled by the designer, and where the flexural, aerodynamic and inertia axes of the wing were very nearly coincident.

With regard to the provision of very high values of torsional stiffness, one had always to consider the increase of structural weight involved, and it was *not* sufficient to state that the values must be very high. Such criteria must be limited in the light of understanding and made no larger than actually desirable from technical considerations.

After asking whether Figs. 2 and 3 were not based mainly on two-spar or multi-spar wings, Mr. Crocombe suggested that it was possible to design completely satisfactory wings on the lower limits of wing density and with lower torsional stiffness values than those indicated.

He also emphasised, from experience, the importance of the mid-aileron measure of torsional rigidity. His experience had been that if single-spar wings

were designed to preclude the possibility of aileron reversal they would not flutter, especially if mass balanced ailerons were used as an additional precaution.

L. W. BRYANT, A.F.R.Ae.S. (*communicated*) : There is one matter connected with wing distortion in flight which it is hoped to make the subject of research at the N.P.L., and that is the effect of wing elasticity on the loading which results from a sudden gust. He did not know whether this question had been considered by Dr. Roxbee Cox, but it is an important example of the kind of effect he explains in §4 of his paper. When a short vertical gust strikes a wing, the latter begins to oscillate with a period approximately that of its natural flexural oscillations. These oscillations are very heavily damped, but the first swing will carry the wing beyond the displacement corresponding to the load which the gust would produce on a rigid wing. Using some figures calculated some time ago by Dr. Duncan, he estimated that in the case of an aeroplane for which a 30 ft./sec. vertical gust would produce a sudden load represented by 3g. if the wings were rigid, elastic wings would give about 4.5g., whilst an accelerometer in the body at the c.g. would register a maximum of 4g. This would mean that accelerometer records would give a fair approximation to the loads likely to be encountered in gusts, but that the strength of gust required to produce the acceleration recorded would be overestimated by about 50 per cent. The effects of torsional elasticity and the complication introduced by the pitching of the aeroplane subjected to gusts of different structure provide an important field for mathematical investigation.

REPLY TO DISCUSSION

Dr. ROXBEE COX, replying to the discussion, thanked Dr. Duncan for his useful comments on the lecture and agreed with him that mass balancing was an extremely important feature to introduce into the design of aeroplanes, and one which in the end permitted definite economy in the structure weight. He was glad to learn from Dr. Duncan of an instance of pure wing flutter, although, of course, it was not a case of pure wing flutter in flight, but in a wind tunnel, the wing, however, although perhaps not representative of design practice, approximated in size to a real wing, and the occurrence confirmed his belief that pure wing flutter was a disability to be guarded against.

Dealing with Dr. Duncan's remark in connection with Figs. 5 and 6, he could not agree that they gave a false impression. It was important to realise that the necessary wing torsional stiffness to prevent loss of lateral control *as measured at the mid-aileron position* decreased with increase of taper. Dr. Duncan's remarks implied that taper in wing plan form meant corresponding taper in the cross sections of the wing structure. This was not necessarily true. Even if it were, then, though *tip* stiffness would decrease with taper roughly in the way indicated by the curves of Fig. 6, *mid-aileron* stiffness, which is our criterion, would decrease scarcely at all. In other words, the provision of the minimum stiffness required to avoid loss of lateral control is likely to be less difficult in wings of tapered plan form.

With regard to Dr. Duncan's question on the stiffness of ribs, he said that if one were going to provide only *one* truly stiff rib near the wing tip, he believed it would be better to aim at making it flexurally stiff rather than torsionally stiff. For a single flexurally rigid rib was of more value than a single torsionally rigid rib, and an *actual* flexurally stiff rib approximated in its behaviour to a flexurally rigid rib much more closely than an *actual* torsionally stiff rib could to a torsionally rigid rib. On the other hand, adding further flexurally stiff ribs when one was already employed at the tip was of little value, whereas every torsionally stiff rib added definitely improved the wing stiffness. The best arrangement in practice, having regard to weight as well as to stiffness considerations, might well prove to be a flexurally and torsionally stiff rib near the wing tip, and torsionally stiff ribs where drag struts would normally occur.

He thanked Dr. Lachmann for his review of work done in other countries on some of the problems discussed in the lecture. He agreed with Dr. Lachmann that more exact criteria of stiffness than were provided by the statistical method described in the lecture were desirable, but no one could provide them. Dr. Küssner's work led to criteria for use in connection with pure wing flutter; his (the lecturer's) procedure was designed for use in connection with wing-aileron flutter. Moreover, Dr. Küssner's criteria also depended upon statistical data. Mr. D. Williams[5] had recently developed the work of Frazer and Duncan, and it appeared possible from his investigations to predict pure wing flutter critical speeds without the elaborate frequency measurements made in Germany. However, pure wing flutter was not yet a pressing problem in this country. No instance of its occurrence in flight here was known. With the work of Küssner, Frazer, Duncan and Williams available, we were well enough equipped to ensure that it never did occur.

The importance of the positions of the axis of inertia, the axis of independence, the flexural axis, and the quarter chord axis was of course fully realised. In preparing the present lecture he had, however, deliberately restricted himself as far as was possible to one parameter-wing stiffness. The influence of the other parameters had been exhaustively discussed[1, 2] by Mr. Frazer and Dr. Duncan.

Commenting on the point that the German methods gave for the particular case mentioned by Dr. Lachmann a critical flutter speed very close to the critical speed by the reversal speed formula developed by Mr. Pugsley and himself, Dr. Roxbee Cox considered that it would be very dangerous to assume that the reversal speed formula could be regarded as in any sense a flutter criterion. The agreement noticed by Dr. Lachmann must have been fortuitous; there were important factors affecting critical flutter speed which had no influence on critical reversal speed.

He was a little puzzled at Dr. Lachmann balancing two-spar construction *against* skin-covered construction. The latter so frequently *was* two-spar construction (*e.g.*, Klemm, Fokker, Miles Hawk, Percival Gull), and the stiff rib advantages could always be utilised when two spars were present. Incidentally, it might be justly remarked that for small aeroplanes skin covering was not economical in weight, and he thought that for such craft the fabric-covered two-spar wing was second to none. He was quite familiar with the work of Biezeno, Koch, Koning, von Fakla and others on the stiff rib problem. References to this work were given in his R. and M. 1436.[12] The problem had received attention in Japan, Poland and France, as well as Holland and Germany. In none of this work, however, had he noticed reference to useful approximate methods[12] (*cf.* §6 of the lecture) or to the *torsionally* stiff rib.[13]

With regard to Dr. Lachmann's remarks on the calculations of two-spar skin-covered wings, he disagreed that Bredt's formula alone could be used to give satisfactory results. It would be quite safe to design the *skin* by it, but the maximum bending moments in the spars, especially near the wing root, would be underestimated.

As was pointed out by Mr. Pollard, the word "fall" should be "rise." He had noticed the error and it would be corrected for the Journal. He thought it might be true that a limited amount of perforation of the skin near the wing root was unlikely to have a serious effect on torsional stiffness. The conditions of connection between skin and spars, and skin and fuselage, however, sometimes meant that $K\ (d\theta/dx)$ (Fig. 18) was not zero at the root, and that shear stresses due to axial constraint were induced there. From a strength point of view, therefore, holes in the skin might be very undesirable.

Professor Bairstow's remarks were extremely interesting. He hoped that aeroplane designers would comment upon them. In answer to Professor Bairstow's leading question, to the best of his belief all the stiffness data represented in Figs. 2 and 3 was measured or calculated by the R.A.E. He hoped the paper

would direct attention to the considerable volume of work listed in Appendix III, which, taken piecemeal, was perhaps a little difficult to assimilate.

He was not sure that he appreciated Mr. Scott Hall's point of view. The strength of a structure to resist *steady* loads was determinable without reference to its distortion under those loads. But the strength against loads which varied with the structural distortion or which produced oscillation of the structure clearly depended on the stiffness of the structure, and, in the latter case, on its mass as well. Whether the stiffness should be high or low, or neither, depended on the duty of the structure. From Mr. Scott Hall's experience, boats should be " easy." Quite definitely, for safety in torsion, aeroplane wings should tend to be stiff. But in flexure, so long as aileron mass balance was embodied and the various important axes correctly disposed, the wing could be quite flexible. He believed that flexibility in flexure might be a good thing, as in sudden gusts the wing would tend to " run away " from the suddenly applied loads, and thereby relieve itself. But whatever the torsional properties best suited to gusts, it is not possible to ignore the consideration of flutter, lateral control and stability, which demand torsional stiffnesses of calculable amounts.

The 11 aeroplanes of Fig. 3 are all included among the 21 of Fig. 2. For the remaining 10 he had not torsional data suitable for inclusion in Fig. 3. That 5 out of the 21 have fluttered has not the significance suggested by Mr. Scott Hall. The 5 represent a large percentage of the British types which have fluttered, while the remaining 16 should be regarded as *any* 16 for which data happened to be available. For further information, R. and M. 1505 should be consulted.

No case of wing flutter on an aeroplane with correctly mass-balanced ailerons was known to the lecturer. Mass balancing is of course a much better way of dealing with flutter prevention than is increase of stiffness. But flutter is but one of a number of menaces; several others are mentioned in the lecture, and mass-balancing is no cure for *them*.

It was interesting to hear from Dr. Thurston that there was a mass of data still unused at Farnborough. He would make a point of looking for it. He believed that his reply to Mr. Scott Hall was also relevant to Dr. Thurston's comments.

Mr. Spencer's interesting remarks drew attention to a very important matter —the translation of the results of investigations described in the lecture into terms of airworthiness. The stress calculator would have to be wary. Allowance for the " rib effect " might indicate a reduction in scantlings, but allowance for the effect of distortion on aerodynamic loading would indicate an increase; he would have to balance these effects against one another. As Mr. Spencer pointed out, the rib action, generally omitted from calculations, was automatically given due credit in a strength test. But should not then the effect of distortion on loading be allowed for too? In other words, in a strength test on a wing, should not the load system be appropriately varied as the deflections increased? This might be a little awkward! Perhaps, if and when such refinements were contemplated, calculation would prove the less troublesome procedure after all.

Mr. Radcliffe made a very important point. It would be very dangerous to apply the methods described in the lecture uncritically. But when refined methods were used to obtain accurate loading conditions, he felt that refinements in stressing methods were justifiable.

Fig. 15 was the result of calculations. The general theory on which these calculations had been made had been thoroughly checked by tests on a wing of similar type to that concerned in Fig. 15 and the agreement between test and calculation had been excellent. He considered that Fig. 15 could be accepted as representative of a biplane with metal box spars and stout ribs firmly connected to them.

He had no information readily available on the comparative torsional stiffnesses of dumb-bell and box type metal spars. Probably the dumb-bell type of spar was torsionally less stiff than the box type associated with Fig. 15, but providing its torsional stiffness could be found by test or calculation, the same sort of calculation as was used to produce Fig. 15 could be made for the wing embodying it.

Mr. Cornwall's point of view was undoubtedly logical. If a monoplane plotted well above the danger lines in both Figs. 2 and 3, then to be compelled to fit mass balance was undoubtedly a little hard. But in his experience of modern monoplanes, which not improbably included the monoplane referred to by Mr. Cornwall, the criteria were never sufficiently above (a margin of safety being essential) the danger lines in *both* diagrams to warrant, in his opinion, dispensing with mass balance. That, *with* mass balance, some were unnecessarily stiff might be argued. That probably meant that had mass balance been part of the original design, weight would have been saved. To have to fit mass balance when it was too late to save weight elsewhere, was an annoyance which would occasionally occur during the transition to *ab initio* mass balancing, which was definitely economical of weight.

Finally, Dr. Roxbee Cox agreed with Mr. Crocombe on the importance of the reversal of control portion of the paper. We could decide for a particular aeroplane on a reversal speed suitably in excess of the highest speed at which it could fly. We were now in a position to find the mid-aileron stiffness dictated by this speed. And with most forms of wing construction we were in a position to calculate for the achievement of this stiffness. That this calculation was particularly easy in single-spar construction was true, and he agreed with Mr. Crocombe that the single-spar wing of tapered plan form had a lot in its favour.

He also agreed that just to ask for high stiffnesses was useless. The work described in the paper was directed to finding quantitative minima. Necessarily, most of the aeroplanes concerned in Figs. 2 and 3 in the paper had two-spar wings. But the theory on which the figures are based is equally applicable whatever the number of spars, and they can be regarded as guides to the stiffness of single-, two- or multi-spar wings. He believed it would be unusual to find a wing whose stiffness had been decided by reversal of control considerations stiff enough for mass balance to be dispensed with.

Answer to communicated contribution.—I am extremely interested in Mr. Bryant's written contribution to the discussion. In collaboration with Mr. D. Williams, I have considered the effect of wing elasticity on the wing loading resulting from a sharp-edged gust. Our very simple investigation, which evaded consideration of torsional stiffness, had indicated *inter alia* that the ratio of the maximum wing load experienced in the gust to the wing load before the gust increases with increase in wing flexural stiffness, that cockpit accelerometer readings always underestimate the maximum wing load in a gust, and that except for subnormal stiffnesses, the rigid wing assumption was optimistic. We found discrepancies between the results of rigid and elastic wing assumptions of the order quoted by Mr. Bryant only for abnormal stiffnesses, but at normal stiffnesses the differences were sufficiently serious.

The 569th Lecture read before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

Fourth Meeting, First Half, 69th Session

The Fourth Meeting of the first half of the 69th Session of the Royal Aeronautical Society was held at the Royal Society of Arts, Adelphi, London, W.C.2, on Thursday, November 30, 1933. In the chair, Mr. E. F. Relf, F.R.Ae.S., Member of Council.

The Chairman: It gave him great pleasure to introduce Dr. W. J. Duncan, who had been working in his department for some eight years. Dr. Duncan came to the National Physical Laboratory in 1926, after a distinguished career at University College, London. The first work Dr. Duncan did soon after he joined the Laboratory was to help Mr. Frazer in investigations on wing flutter at first, and other kinds of flutter—such as airscrew flutter—afterwards, and in that he had shown himself to be an exceedingly able investigator both from the theoretical and experimental points of view. When the Meopham accident led to the discovery of buffeting and it was decided to carry out investigations into that phenomenon, Dr. Duncan was given charge of that work and was practically solely responsible for it, and it was that work about which he was to speak that evening. At present, Dr. Duncan was pursuing his investigations into other forms of flutter, particularly the flutter of servo-control systems and of airscrew blades, which had not yet been fully cleared up.

TAIL BUFFETING

BY

W. J. DUNCAN, D.Sc., A.M.I.Mech.E.

1. Introduction

The subject of tail buffeting first came into prominence in this country early in 1931 when the Accidents Investigation Sub-Committee of the Aeronautical Research Committee issued their report (1) on the accident to a Junkers monoplane at Meopham, Kent. The Sub-Committee gave it as their opinion that tail buffeting was the probable primary cause of this accident, and recommended that the phenomenon should be investigated. At this time tail buffeting (Leitwerkschütteln) was quite well known in Germany, where the low-wing monoplane, which is peculiarly susceptible to this trouble, was a popular type of aircraft; and some full-scale experiments on the subject had already been made by the Deutsche Versuchsanstalt für Luftfahrt. The findings of the Accidents Investigation Sub-Committee caused an intensive study of buffeting to be undertaken both in Germany and in this country, and the enquiry was also taken up in the United States at a later date. As a result of these studies tail buffeting is now quite well understood, and methods for its avoidance have been established.

As reference has been made to the Meopham accident, it is only fair to add that the German aeronautical authorities do not agree with the finding that the primary cause was tail buffeting. In their view (2, 3) the primary failure pro-

bably occurred in the wings as the result of a too rapid pull-out from a dive, but they do not go so far as to assert that fracture of the tail of the aeroplane by buffeting is an impossibility. Whatever view may be taken as to the causation of this particular accident,[1] it cannot be denied that tail buffeting, when at all severe, is an intolerable nuisance, and a source of deterioration which may eventually prove dangerous.

The present paper aims primarily at giving a general account of the investigations on buffeting conducted at the National Physical Laboratory in recent years,[2] but references to foreign work on the subject are also given. While I am solely responsible for this paper, many members of the laboratory staff have shared in the investigation. Prominent among these are Mr. R. A. Frazer, who took a leading part in the earlier work on buffeting, and Mr. D. L. Ellis, who has been largely responsible for the more recent experimental work. I should like to take this opportunity to say what a pleasure it has been to collaborate with these and other colleagues.

PART I.

BUFFETING IN THE WAKE OF AN AEROFOIL

2. *Definition of Buffeting*

The term " buffeting " is defined (5) as " the more or less irregular oscillation of some part of an aeroplane (*e.g.*, the tail) produced by the incidence upon it of the eddying wake from some other part."[3] Now it is clear that we cannot hope to understand buffeting thoroughly without some acquaintance with the " natural history " of a typical wake.[4] Accordingly I shall give, as a preliminary, a very brief and somewhat idealised description of the wake of a bluff cylindrical body, since the characteristic phenomena are here particularly plain.

3. *The Wake of a Bluff Cylindrical Body*

It is a matter of experience that all long cylindrical bodies with compact and blunt-ended sectional forms give rise to eddying wakes of the same general type when placed in a uniform (and not excessively slow) current of air. Immediately behind the body there is a region of " dead air " where the flow is greatly retarded. This region is separated from the freely flowing outer stream by a pair of narrow bands of intense vorticity, where the velocity gradient normal to the direction of flow is very high. These narrow bands or " vortex sheets " are, however, unstable, and at a short distance downstream they " roll up " into a series of almost evenly spaced and equal eddies whose axes are parallel to the generators of the cylindrical obstacle. The centres of the eddies travel down a pair of slightly divergent and curved lines, and the arrangement of the eddies is alternate, *i.e.*, the centres of the eddies of the upper row are opposite the middles of the spaces of the bottom row. Such an arrangement is known as a vortex street, and it has two characteristics which are important from the present

[1] Another accident involving break-up of a machine in the air has been considered to be probably due to tail buffeting. The aeroplane involved was a thick winged Italian monoplane, and an account of the inquiry will be found in Ref. 4, where various instances of severe tail buffeting are recorded.

[2] The work is fully described in Refs. 5 and 6.

[3] The purist may object that the word " buffeting " is here applied to mean the *motion* of the tail, whereas with ordinary usage it should mean the *external agency* which causes the motion. Mr. R. A. Frazer and myself proposed the term " succussion " for the motion produced by the buffeting, but this technical use of the word has not met with general acceptance.

[4] The natural philosophy of the eddying wake can hardly yet be considered to be born.

point of view. Firstly, since the eddies are of roughly equal strength, are evenly spaced, and move with nearly uniform speed, it follows that the deviations from uniformity of flow in and near the wake will be approximately periodic in time. The number of eddies in one of the rows which passes a fixed point in one second is called the eddy frequency, and this is also the frequency of the fluctuations of the flow.[5] Secondly, the deviations of the flow are predominantly two-dimensional, *i.e.*, they take place in planes perpendicular to the generators of the cylinder.

The régime described above persists for some distance downstream, but the individual eddies tend to diffuse outwards and intermingle, while the fluctuations of the flow become more and more clearly three-dimensional as the eddies move downstream. The characteristics of the flow in the more remote parts of the wake are described in Mr. Fage's lecture (7) on "The Behaviour of Fluids in Turbulent Motion," but these are not important in relation to tail buffeting, and will not be discussed here.

One other important feature of the wake region remains to be mentioned. When explorations are made with a "total-head tube," it is found that the total-head in all parts of the free stream has a constant value, but that the total-head in the wake is reduced. The boundaries of the region of low total-head are moderately well defined, and it is convenient to describe this region as the "total-head wake." It is found that large fluctuations of the flow occur outside this total-head wake.

4. *The Wake behind an Aerofoil of Infinite Aspect Ratio*

The size and other characters of the wake of an aerofoil depend largely on the angle of incidence. For convenience let us begin with a very large incidence (say double the stalling angle), and let us examine the sequence of events as the incidence is progressively reduced, while the wind speed is kept constant.

At the initial large incidence the aerofoil behaves like a typical bluff body, and the wake is of the type already described. As the incidence is reduced towards the stalling angle, the wake becomes narrower, the frequency of the eddies rises, and the eddying motion tends to become more confused and irregular. On passage through the stall there is a large and sudden contraction of the wake (see Fig. 1) with a correspondingly large increase in the eddy frequency. Concurrently the eddying becomes markedly less regular, and indeed it becomes a matter of difficulty to ascertain the predominant frequency of the eddies, since they do not occur at equal time intervals. When the incidence is further reduced towards the no-lift angle, the wake continues to become narrower, and the eddying progressively less important.

The experimental study of the fluctuations of the airflow which occur in and near the wake is most conveniently carried out with the aid of the hot-wire anemometer (8, 9, 10). This instrument consists essentially of a short length of fine platinum wire bridging a suitable forked support. A constant potential difference is maintained between the ends of the wire, and this is so chosen that the resulting current heats the wire to the temperature which is most suitable for the particular measurements. When the heated wire is exposed to an air current it is cooled; its resistance therefore falls and the current rises in the inverse ratio. So long as the applied P.D. is constant and the attitude of the wire in the airstream is unaltered, the current is a definite function of the speed of the airstream. Consequently an ammeter in the circuit can be calibrated to give the airspeed directly. Provided that the platinum wire is of very small thickness, its temperature will respond to even very rapid variations in the airstream, and these variations will be more or less faithfully reproduced in the fluctuations of the electric current. In order to obtain a permanent record for examination

[5] Fluctuations of double frequency may occur in the centre of the wake (see Ref. 8).

and measurement an Einthoven string galvanometer provided with a dropping plate may be used.[6]

The response of a heated wire to small disturbances in an otherwise uniform airstream depends on the attitude of the wire. In general the cooling effect of the component of flow parallel to the wire is small compared to that due to the perpendicular component. Suppose that the mean direction of the flow is horizontal, and first let the wire be placed with its length parallel to the flow. Then the instrument will record the transverse fluctuations of the flow. If, on the other hand, the wire is horizontal but at right angles to the general direction of the flow, then it will respond to the longitudinal and vertical transverse fluctuations only.

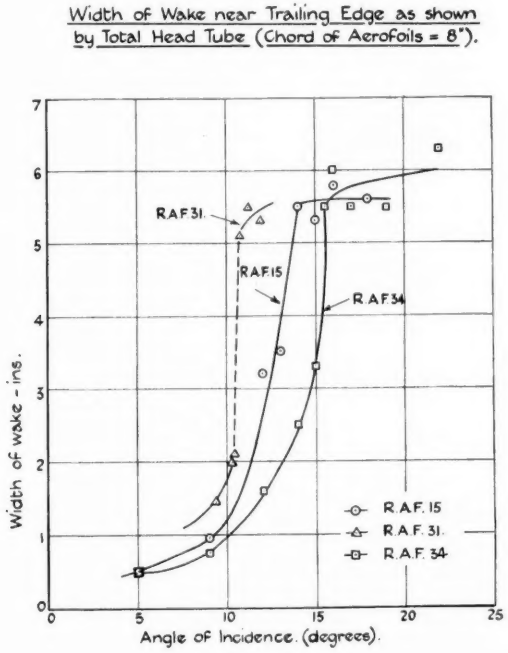


FIG. 1.

Some representative records[7] of the speed fluctuations in or near the wake of a R.A.F. 31 aerofoil are reproduced in Fig. 2. The hot wire was placed with its length parallel to the span of the aerofoil and at the position stated below each record. Fig. 2A refers to an incidence immediately below the stall and illustrates in an interesting way a sudden change from a régime with only small fluctuations to another in which they are much larger. This figure also shows clearly the great irregularity of the fluctuations for incidences below the stall. Fig. 2B refers to an incidence immediately above the stall, and shows that the fluctuations have become appreciably more regular, and of much lower frequency. (Attention may be drawn to the differences of scale in the figures.) For a

[6] It is usually necessary to amplify the current fluctuations. For details of the amplifiers and other electrical accessories, see Refs. 8, 9, 10.

[7] The records were obtained by Messrs. C. Salter and J. A. Beavan, working under the direction of Mr. L. F. G. Simmons.

slightly higher incidence (see Fig. 2c), the frequency is only slightly different, but the fluctuations are decidedly more regular in their incidence in time, although showing rather large capricious variations of amplitude.

The results of some measurements of the fluctuations in the wake of a R.A.F. 31 aerofoil of 8-inch chord are given in Tables I and II. It will be seen that the following relations hold very roughly :—

(1) The magnitude of the speed fluctuation at a given incidence is proportional to the wind speed.
(2) The eddy frequency at a given incidence is proportional to the wind speed.
(3) The eddy frequency at a given wind speed is inversely as the width of the wake.

TABLE I.

VARIATION OF EDDY FREQUENCY AND MAXIMUM SPEED FLUCTUATION WITH WIND SPEED.

Incidence 15 deg. Position 2 chords behind and 0.36 chord below trailing edge of aerofoil.

Wind Speed. ft./sec.	Frequency cycles per sec.	Frequency. / Speed.	Maximum Speed Fluctuation.* ft./sec.	Speed Fluctuation. / Speed.
20	16	0.80	13.2	0.66
30	25	0.83	12.4	0.41
35	30	0.86	19.8	0.57
40	32	0.80	21.8	0.55

TABLE II.

VARIATION OF EDDY FREQUENCY AND WIDTH OF TOTAL-HEAD WAKE WITH INCIDENCE.

Width of wake measured at 0.31 chord behind trailing edge of aerofoil. Wind speed 30 ft./sec.

Incidence. deg.	Width of Wake. ft. (W).	Frequency cycles per sec. (f).	Wf / V.
9.4	0.186	67.5	0.42
11.9	0.472	27.3	0.43
15.0	0.562	25.5	0.48

The first two of these relations follow from dimensional theory, provided that aerodynamical scale effect is negligible. The third is suggested by Kármán's theory of the stability of a vortex street.

5. *Buffeting in the Wake of an Aerofoil of Infinite Aspect Ratio*

Before passing to an account of the results of buffeting tests made with aerofoils of infinite aspect ratio, I shall give a brief description of the apparatus used in the experiments at the National Physical Laboratory. Fig. 3 shows the general arrangement. The aerofoil under test spans the wind tunnel and can be set at any desired incidence. The " detector," which plays the part of the tail-plane of an aeroplane, is supported from a vertical streamline strut, and can be fixed at any selected position. On account of the optical arrangements for recording the motion of the detector it is not convenient to move the latter along the tunnel, and the distance of the detector behind the trailing edge is varied by moving the aerofoil.

* On account of the short duration of the record these maxima are subject to a rather large random sampling error.

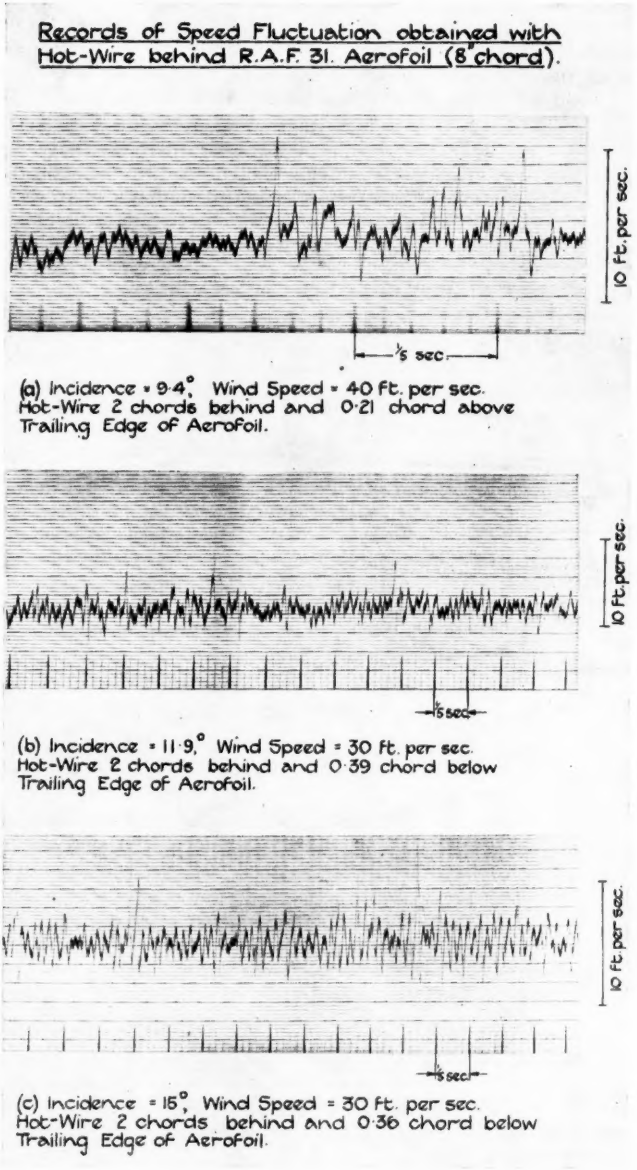

Records of Speed Fluctuation obtained with Hot-Wire behind R.A.F. 31. Aerofoil (8" chord).
10 ft. per sec.
⅕ sec.
(a) Incidence = 9·4°, Wind Speed = 40 ft. per sec. Hot-Wire 2 chords behind and 0·21 chord above Trailing Edge of Aerofoil.
10 ft. per sec.
⅕ sec.
(b) Incidence = 11·9°, Wind Speed = 30 ft. per sec. Hot-Wire 2 chords behind and 0·39 chord below Trailing Edge of Aerofoil.
10 ft. per sec.
⅕ sec.
(c) Incidence = 15°, Wind Speed = 30 ft. per sec. Hot-Wire 2 chords behind and 0·36 chord below Trailing Edge of Aerofoil.

FIG. 2.

The design of the detector (see Fig. 4) was based on the observation that flexure of the tailplane is the most important kind of deformation in buffeting.[8] It further appeared desirable to prevent any torsional motion of the detector plane for the following reasons:—

(1) If torsion took place there would be a change in the lift not directly related to the fluctuations of the airflow.

(2) If torsion could occur the detector would possess at least two effective degrees of freedom, and would therefore have two distinct resonance frequencies. This would lead to complications in the interpretation of the results obtained with the detector.

General Arrangement of Apparatus.

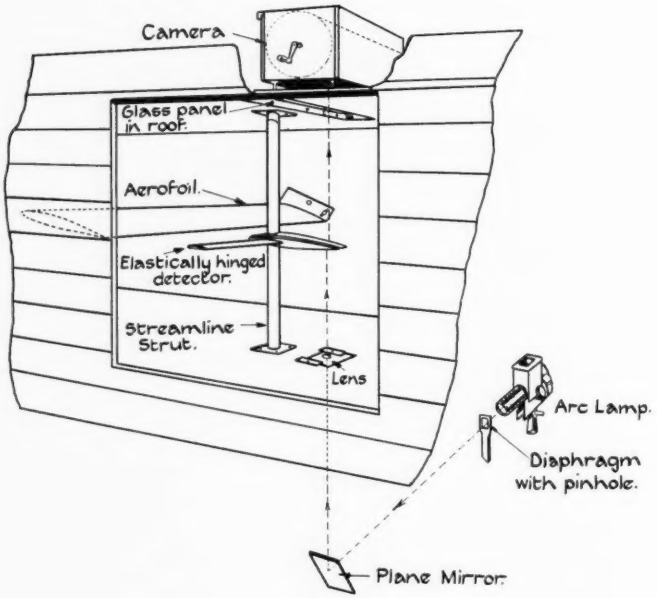


FIG. 3.

In accordance with these considerations the aerofoil of the detector was made of hard wood, with some lightening holes covered with doped silk. At the root the aerofoil was firmly secured to an elongated base-piece provided with a pair of widely separated steel spring hinges. The flexural stiffness could be readily varied by changing the hinge springs, and the torsional stiffness was always relatively very high.

The motions of the detector were recorded photographically. Light from an arc lamp was focussed on a pin-hole and then reflected vertically through a lens

[8] Torsion of the fuselage may also be important, but the resulting motion of the tailplane is of the flexural type.

fixed in the floor of the tunnel (see Fig. 3). The emergent ray impinged upon a small plane mirror of stainless steel attached to the movable base-piece of the detector (see Fig. 4). The ray was reflected horizontally upon a similar fixed plane mirror, and then vertically through a window in the roof of the tunnel. When the shutter of the camera was opened, the beam of light entered the camera through a long slit and came to a focus on the surface of bromide paper carried on a cylindrical drum. Since the mirrors used were plane, the focus of the rays was not altered when the vertical position of the detector was changed.

Results of a typical set of explorations made with the detector are given in Fig. 5, which refers to a R.A.F. 31 aerofoil of 8-inch chord set at an incidence

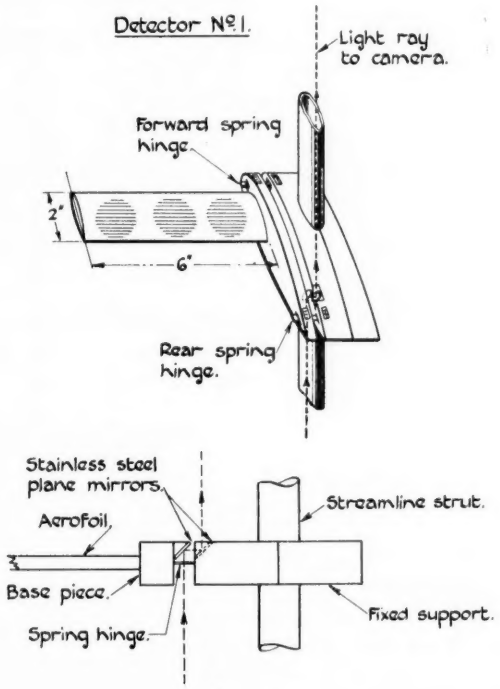


FIG. 4.

just above the stall. The full lines in the diagram are contours of equal intensity of buffeting, which is measured by the greatest range of movement of the tip of the detector during a standard exposure of one minute, while the chain dotted lines are the approximate boundaries of the "total-head wake." An examination of this diagram, which is quite typical of a stalled aerofoil, leads to the following conclusions:—

(1) The buffeting is most severe within the region where the total-head is reduced, but only slightly less severe buffeting occurs just outside this region.

(2) Within the range of practicable positions for a tailplane, the buffeting decreases rapidly as the tailplane is moved downwards.

(3) The fore-and-aft position of the tailplane has only a slight influence on the intensity of the buffeting.

6. *Critical Influence of the Angle of Incidence*

The most important of all the variables which govern the intensity of buffeting is the incidence of the aerofoil which creates the disturbed wake. This is very clearly brought out by Fig. 6 which shows the intensity of buffeting behind a R.A.F. 31 aerofoil for a range of vertical positions of the detector, and for four angles of incidence ranging from 6° to 15°. The stalling angle for this aerofoil is 10.6°, and the curves show that there is a sudden and very large increase in the buffeting when the stalling incidence is exceeded.[9] Further increase of the incidence from 11.9° to 15° does not greatly affect the buffeting, except possibly when resonance effects are prominent (see §7).

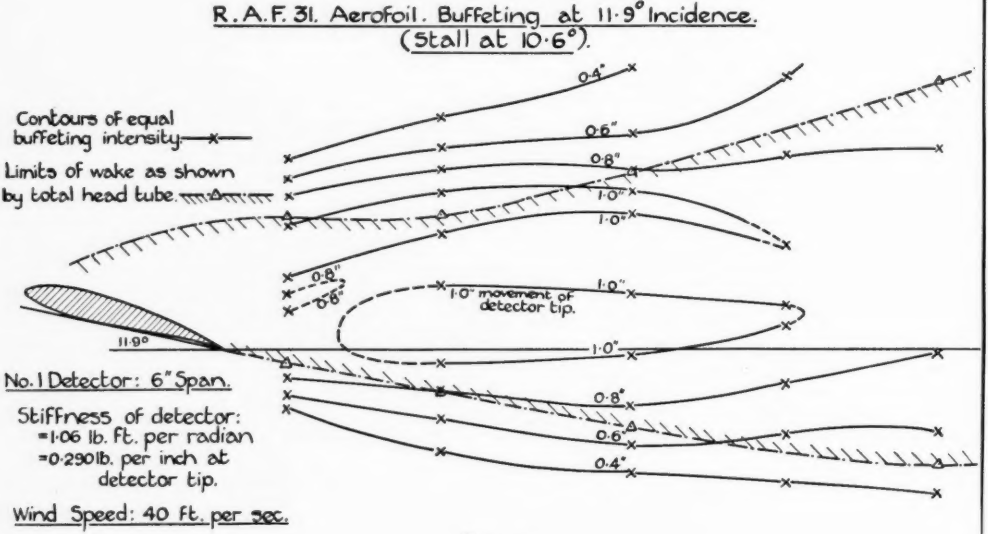

R.A.F. 31. Aerofoil. Buffeting at 11·9° Incidence.
(Stall at 10·6°).
Contours of equal buffeting intensity.
Limits of wake as shown by total head tube.
0·4"
0·6"
0·8"
1·0"
1·0" movement of detector tip.
11·9°
No. 1 Detector: 6" Span.
Stiffness of detector:
=1·06 lb. ft. per radian
=0·290 lb. per inch at detector tip.
Wind Speed: 40 ft. per sec.

FIG. 5.

The records of the fluctuations of the airflow in the wake obtained with the hot wire indicate that only a part of the great increase of buffeting which accompanies passage through the stall is attributable to an increase in the magnitude of the fluctuations. It appears that those which occur below the stall are too rapid and too irregular to evoke a strong response from the detector.

7. *Resonance Effects in Buffeting*

I have already explained that the disturbances in the wake of a bluff cylindrical body, although somewhat irregular, have a predominating frequency, and that the disturbances in the wake behind an aerofoil at a very large incidence are of a similar nature. On account of the existence of this predominant frequency in the disturbances, we should expect to find evidence of the occurrence of resonance in the buffeting caused by aerofoils, at any rate for incidences well above the stall. This expectation proves to be well founded.

[9] The suddenness of the transition is usually much less for a wing-body combination than for an aerofoil alone. This is due to the wing stalling by stages as the incidence increases. (see §14.)

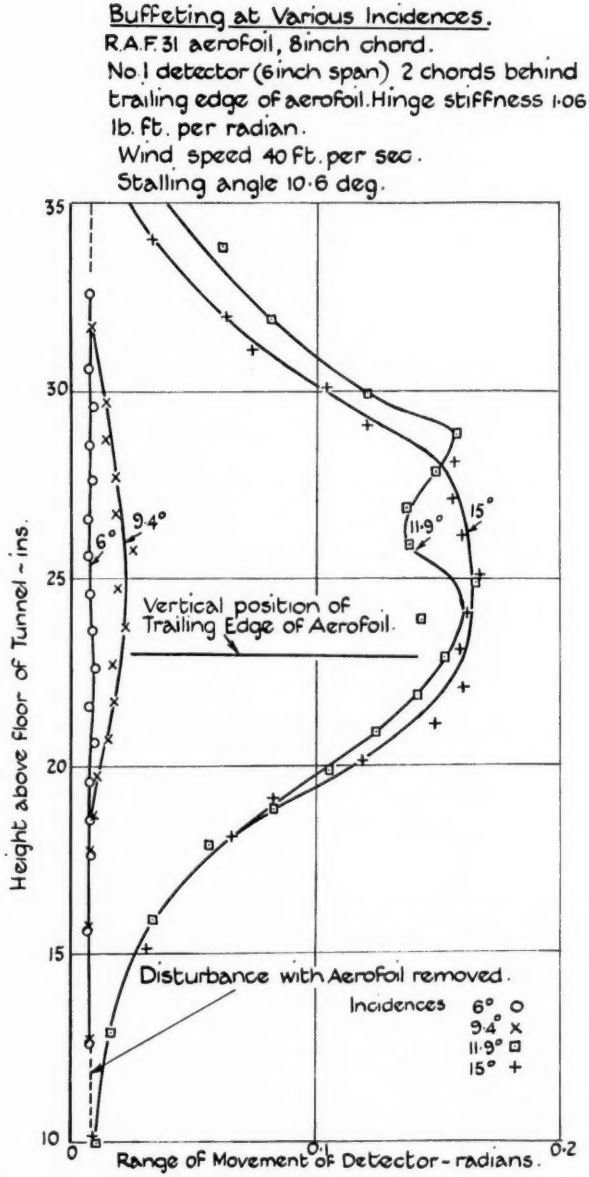

Buffeting at Various Incidences.
R.A.F. 31 aerofoil, 8inch chord.
No. 1 detector (6inch span) 2 chords behind trailing edge of aerofoil. Hinge stiffness 1·06 lb. ft. per radian.
Wind speed 40 ft. per sec.
Stalling angle 10·6 deg.
Height above floor of Tunnel - ins.
35
30
25
20
15
10
0
0·1
0·2
Range of Movement of Detector - radians.
6°
9·4°
11·9°
15°
Vertical position of Trailing Edge of Aerofoil.
Disturbance with Aerofoil removed.
Incidences 6° O
9·4° ×
11·9° □
15° +

FIG. 6.

Fig. 7 shows the results of a series of tests in which the stiffness of the spring hinges of the detector was varied gradually, while all other factors were kept constant. The abscissa in the diagram is the hinge stiffness and the ordinate is the product of the stiffness and the range of the buffeting. It will be seen that for the chosen angle of incidence, which is 4.4° above the stall, the curve exhibits a rather sharp peak where the stiffness is about 0.52 lb. ft. per radian. Now the moment of inertia of the detector about its hinge axis was found to be 2.19×10^{-5} slug ft.^{2}. Hence the natural frequency of the detector in the condition of resonance was

$$f = 1/2\pi\sqrt{(0.52/2.19 \times 10^{-5})} = 24.5 \text{ cycles per sec.}$$

The predominant eddy frequency as found by examination of the records of the fluctuations obtained with the hot wire was 25.5, which is in satisfactory agreement with the resonance frequency.

Similar tests were made at an incidence of 11.9° (*i.e.*, 1.3° above the stall). Some evidence of resonance was obtained, but the peak on the curve had now become very blunt. This result is no doubt attributable to the greater irregularity of the fluctuations at the lower incidence. Search has been made for evidence of resonance when the incidence is below the stalling angle, but hitherto without success. Hence it appears probable that the disturbances in the wake of an unstalled aerofoil are too irregular to give rise to any pronounced resonance effects.

Since tail buffeting is considerably enhanced when resonance occurs, it is clearly most desirable to avoid this condition. Accordingly the following formal recommendation has been made (6):—

> "The rear fuselage and tail unit should be so stiff that all the natural frequencies are much higher than the predominant eddy frequency at the stall."

In amplification of this recommendation it has been said ". . . the possibility of accidental stalling at flight speeds higher than the normal stalling speed should not be overlooked. It is considered that the lowest natural frequency of the tail unit should be not less than twice the eddy frequency at the highest speed at which it appears possible for even momentary stalling to occur. A very rough rule[10] for the estimation of the predominant eddy frequency at the stall is

$$f = 0.8\ V/c,$$

where f = eddy frequency (cycles per sec.),
V = air speed (ft. per sec.),
and c = mean chord (ft.)."

8. *Influence of Wind Speed and of Stiffness at Constant Incidence*

If the detector with its hinges could become completely rigid so that it remained quite stationary under the action of the eddies in the wake, the aerodynamical forces due to these eddies would be proportional to the square of the wind speed, for a fixed incidence of the aerofoil creating the wake. Suppose now that the hinges are very stiff, but not quite rigid. Then the detector will only move very slightly, and the aerodynamical forces on it will be almost the same as before. Consequently the amplitude of the buffeting will be proportional to the square of the wind speed, and inversely proportional to the hinge stiffness.

The simplified conditions postulated above are seldom met, but experiment shows that, provided there is no approach to a condition of resonance, the range of buffeting for a constant wing incidence is roughly proportional to the square of the air speed, and inversely proportional to the stiffness.

[10] See Ref. 5 and various papers cited in Appendix II of that report for further information on the subject. The rule here given is probably correct to within ± 20 per cent.

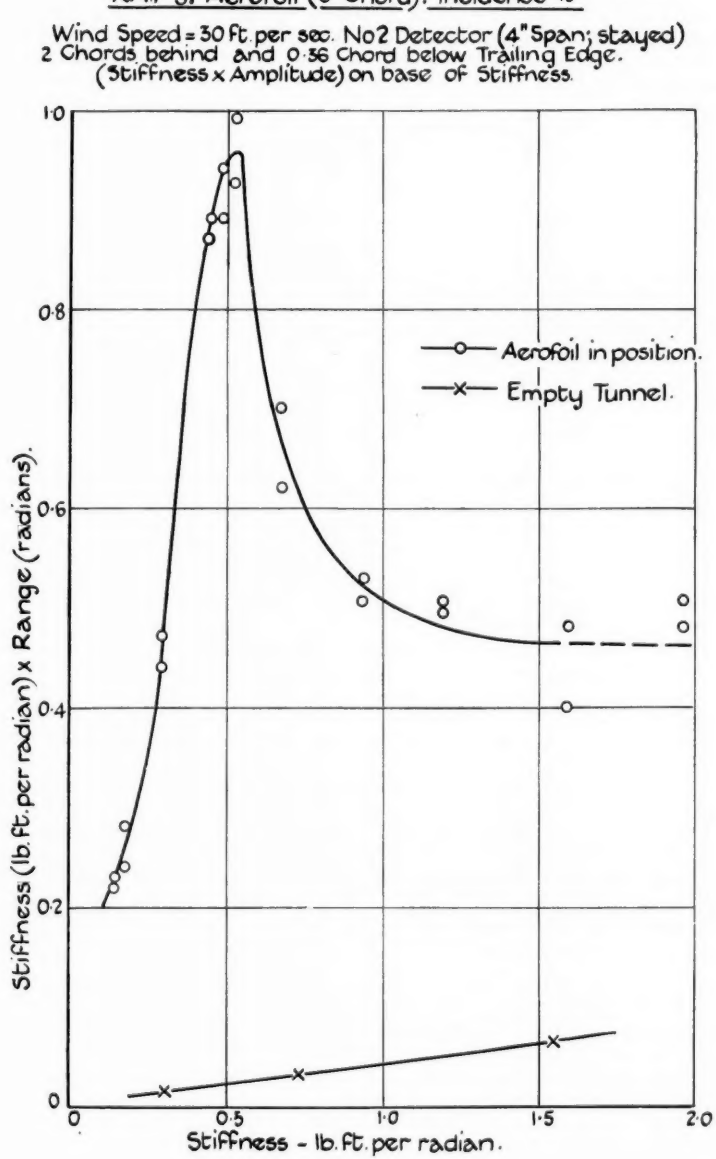

R.A.F. 31 Aerofoil (8" Chord). Incidence 15°
Wind Speed = 30 ft. per sec. No 2 Detector (4" Span; stayed)
2 Chords behind and 0·36 Chord below Trailing Edge.
(Stiffness x Amplitude) on base of Stiffness.
Aerofoil in position.
Empty Tunnel.
Stiffness (lb. ft. per radian) x Range (radians).
Stiffness - lb. ft. per radian.
1·0
0·8
0·6
0·4
0·2
0
0·5
1·0
1·5
2·0

FIG. 7.

9. *Effect of a Sudden Change of Incidence*

It is a matter of some interest and importance to find whether specially severe buffeting accompanies a sudden change of wing incidence, such as might be produced in flight by a sharp up gust, and some experiments on the subject were accordingly carried out, using a R.A.F. 34 aerofoil of 8-inch chord. This aerofoil was mounted on pivots situated at 0.44 of the chord from the leading edge, and arranged to be very quickly moved through any chosen angle by means of a spring operated toggle mechanism provided with a trigger release.

In one set of tests the incidence was increased from 5° to 17° in 1/36 second. The wind speed was 40 ft./sec., so that the movement of the air during the change of incidence amounted to roughly 1.7 wing chords. At the initial incidence of 5° the detector hardly quivered, but immediately after the change of incidence it began to oscillate. The first few swings were, however, always of small amplitude. In one instance the amplitude reached in the sixth swing was roughly equal to the maximum obtained when the incidence was steadily maintained at 17°. As a rule the maximum was reached after a longer interval, and in no case did it exceed the maximum obtained with a steady incidence of 17°.

These experiments tend to show that when incidence increases rapidly the greatest severity of buffeting experienced does not exceed that corresponding to the final incidence under steady conditions.

10. *Comparison of Various Aerofoils*

Systematic and fairly comprehensive tests have been made on the buffeting induced by aerofoils of R.A.F. 15, R.A.F. 31, and R.A.F. 34 profiles (all of infinite aspect ratio). Now we have already seen that the stalling angle is a critical incidence in relation to buffeting, and it is therefore clear that if we wish to discover any similarities in the buffeting characteristics of aerofoils, we must make the comparisons for incidences which bear some kind of corresponding relation to the stalling angles. The tests on the three aerofoils already mentioned show that in the stalled condition the buffeting is very nearly the same both in distribution and intensity; it also appears to be generally true that a further increase of incidence of a few degrees beyond the stalling angle has little effect on the buffeting. The comparison of aerofoils at angles below the stall is complicated by the fact that stalling does not occur with the same suddenness in all cases (see Fig. 1). If, however, the incidences are chosen so that the total-head wake just behind the aerofoil has the same width in all cases, then the differences in the buffeting characteristics are not large, although perhaps rather more definite than for incidences at or above the stall.

We may conclude provisionally that the differences in the buffeting characteristics of aerofoils of infinite aspect ratio are not important. It does not follow, however, that the wing profile has no influence on the buffeting in the case of a wing-body combination.

11. *Influence of a Plane Wall and of a Small Excrescence*

The buffeting in the wake of a wing-body combination is often widely different from that caused by the wing alone at the same incidence. This matter is of great importance and is discussed at length in Part II, but in order to clear the way for the later discussion I shall describe an experiment which shows that the additional frictional drag introduced by the body is not the prime cause of the large effects produced by it.

An aerofoil of R.A.F. 34 profile and 8-inch chord spanned a 4-foot wind tunnel, and a large flat plate of metal was placed above the aerofoil with its plane perpendicular to the span, and therefore parallel to the direction of the airstream. The lower edge of the plate was shaped to fit the upper surface of

the aerofoil. Tests were made at incidences of 8.5° and 12°, and it was found that the presence of the plate had a quite negligible influence on the buffeting.

Another set of tests were performed with the same aerofoil in order to find the effect of a small excrescence placed on the upper surface of a wing. The excrescence consisted of a piece of thin sheet metal 1-inch square fixed to the aerofoil at the point of maximum thickness and with its plane at about 30° to the tangent to the upper surface. When the wing incidence was 12° (or 3° below the stall) the effect of the small plate was to cause complete breakdown of the flow over a large area, and the buffeting in the wake from this region was approximately the same as for a fully stalled wing.

12. Buffeting in the Wake of an Aerofoil of Finite Aspect Ratio

The flow pattern in the neighbourhood of an aerofoil of finite span differs considerably from that which characterises an aerofoil of the same profile but of infinite span. Trailing vortices pass downstream from the aerofoil, and these are most vigorous towards the tips. The downwash induced by these vortices alters the true angle of incidence, and this is in general not constant along the span. Hence it is found that the stalling angle of an aerofoil of finite aspect ratio is not the same as for infinite aspect ratio; moreover stalling does not as a rule occur simultaneously over the whole span.

An illustration of the foregoing facts is provided by some experiments made on an untwisted R.A.F. 31 aerofoil of rectangular plan form and 6 : 1 aspect ratio. The nature of the flow over this aerofoil was shown by the behaviour of wool streamers attached at various points of the upper surface. When the angle of incidence was gradually increased, it was found that breakdown of the flow, as evidenced by the severe agitation of the streamers, began in the middle of the span, but extended over the whole span when the incidence was further increased by about 0.5°. The geometrical angle of incidence when complete breakdown occurred was 11.8°, which is 1.2° above the stalling angle for infinite aspect ratio. Evidently, then, allowance must be made for the differences in the stalling angles when the buffeting caused by aerofoils of finite and infinite aspect ratio is compared.

A series of tests were made using the R.A.F. 31 aerofoil of 6 : 1 aspect ratio for incidences of 10.7° and 13.2°, which may be taken to correspond to 9.4° and 11.9° for infinite aspect ratio. The intensity of the buffeting was measured at a distance of two chords behind the trailing edge of the aerofoil, and at various vertical and horizontal stations. It was found that over the whole central part of the span the buffeting was independent of lateral (spanwise) position; in this region both the greatest intensity of the buffeting and its variation in the vertical direction were closely the same as for an aerofoil of infinite aspect ratio at a corresponding incidence. Towards the tips the intensity of the buffeting decreased rapidly, and it is clear that the rotary airflow due to the trailing vortices is regular and does not give rise to buffeting.

PART II.

BUFFETING IN THE WAKE OF A WING-BODY COMBINATION

13. Preliminary

We have already seen that the buffeting in the wake of an aerofoil is only severe for incidences at or above the stalling angle, when the airflow has "broken down." Evidently then we must expect to find that the severity of the buffeting in the wake of a wing-body combination is largely controlled by the occurrence of a broken-down flow, and the conditions for this must be examined. The experimental study of fluid motion in general has revealed some

useful qualitative principles, and these prove to be applicable to flow around a wing-body combination.

Under ordinary conditions the motion of a fluid is always to some extent turbulent, but the flow is only said to have broken down when the turbulence becomes violent and widespread. Now Prandtl and his co-workers have shown (11) that the breakdown has its origin in the boundary layer of the body or bodies over which the fluid is flowing. When the pressure gradient in the boundary layer in the direction of flow is negative, as in a convergent stream, so that the resultant of the pressures on a fluid element is a force tending to accelerate it, breakdown does not occur; but when this gradient exceeds some small positive value, the flow in the boundary layer reverses, the layer widens rather suddenly, and a general breakdown of the flow occurs. Prandtl has confirmed the important *rôle* of the boundary layer by showing that breakdown can be prevented by sucking away the stagnant fluid in this layer at the critical regions of the boundary.

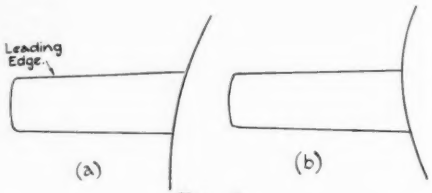


FIG. 8.

It is now clear that breakdown of the flow may be expected to occur where there is a large positive pressure gradient near the boundary, *i.e.*, in the regions where the flow is most divergent. For a typical aerofoil set at a positive incidence, the region of greatest divergence is on the upper surface, and it is here that the flow first breaks down. Now suppose that the aerofoil is intersected by a cylindrical wall with its generators perpendicular to the plane of the aerofoil. If the wall at the rear slopes towards the tip of the aerofoil, as in Fig. 8A, the divergence of the airstream in the critical region will be decreased and with it the tendency to breakdown. On the other hand, if the wall has the reverse slope, as in Fig. 8B, the divergence of the flow will be increased and breakdown will occur for a lower angle of incidence. This simple illustration helps us to understand how the body influences the whole character of the flow over the wings in its neighbourhood (12, 13), and thus vitally affects the buffeting of the tail.

For the purpose of a general investigation of the influence of the body on tail buffeting, systematic tests were made on four different monoplanes of somewhat simplified form (see Fig. 9). The aerofoil was the same in all cases and was of rectangular plan form with 36-inch span, 6-inch chord, and R.A.F. 31 profile. This was fitted to a body of circular section in the high-wing, mid-wing, and low-wing positions, and to a body of D-shaped section in the low-wing position only. In each case the chord line of the aerofoil was parallel to the centre line of the body.

14. Explorations using Wool Streamers

Streamers attached to the wings, body, and tail of an aeroplane have been extensively used and with great success in full-scale studies of the airflow (2, 14, 15). Experiments with streamers cannot adequately replace buffeting tests in which the movements of a tailplane or detector are recorded, but they are always instructive, and they show clearly the conditions under which buffeting tests may be made with the greatest profit. The flow in the vicinity of each of the four model monoplanes described at the end of the last section was explored

with the aid of wool streamers attached to the wings or supported by external wires. In all cases it was found that severe buffeting occurred when the streamers in that part of the airstream which impinged on the tailplane were greatly agitated.

Let us first consider the low-wing monoplane with circular body. When this was tested in the original condition without wing-root fairings of any kind, it was found that the flow in the region close to the body and towards the trailing edge of the wing was highly disturbed, even for small angles of incidence. This

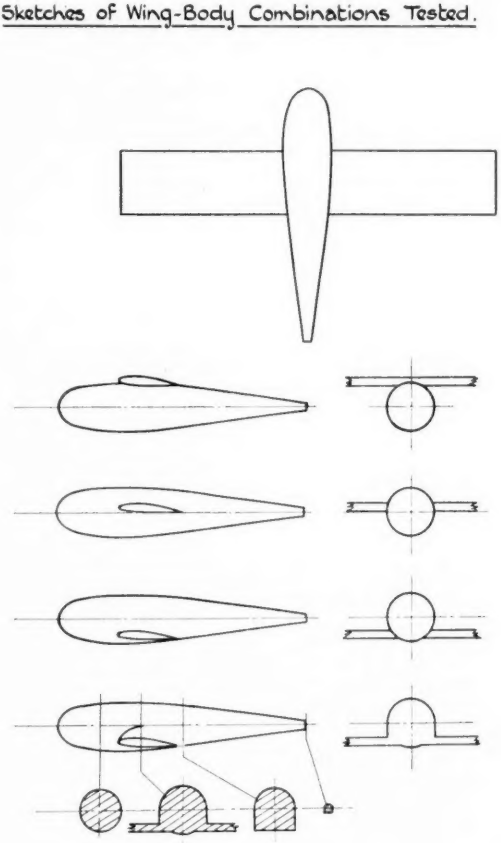


FIG. 9.

can be explained by the rapid divergence of the space between the wing and body. As the angle of incidence was increased, the region of disturbed flow spread forward and outwards along the span, until at an incidence of 12.5° the breakdown had become general, with the exception of a strip at each wing tip about 1 chord wide. When the incidence was further increased by about 0.5° the breakdown suddenly extended over the tip regions also.

The low-wing monoplane with the D-shaped body gave appreciably better results than with the circular body, as would be expected since the divergence

of the flow near the wing root is reduced. Here the flow was smooth all over the wings for all small angles of incidence, but at 6° a slight local disturbance appeared at the trailing edge next the body, and this disturbance extended outwards when the incidence was further increased. At 11° the disturbance at the wing root had become vigorous, and there was *inward* flow along the trailing edge, except near the tip. When the incidence reached 12° the flow broke down over the whole wing. We thus have an illustration of the fact that inward flow along the trailing edge is generally a symptom of the near onset of complete breakdown of the flow.

In the case of the mid-wing monoplane with circular body the flow was quite smooth up to 7.5° incidence, but at 8° spasms of unilateral breakdown of 2 or 3 seconds' duration began to appear at intervals of about 10 seconds in a region extending outwards from the wing root by about one chord[11] (see

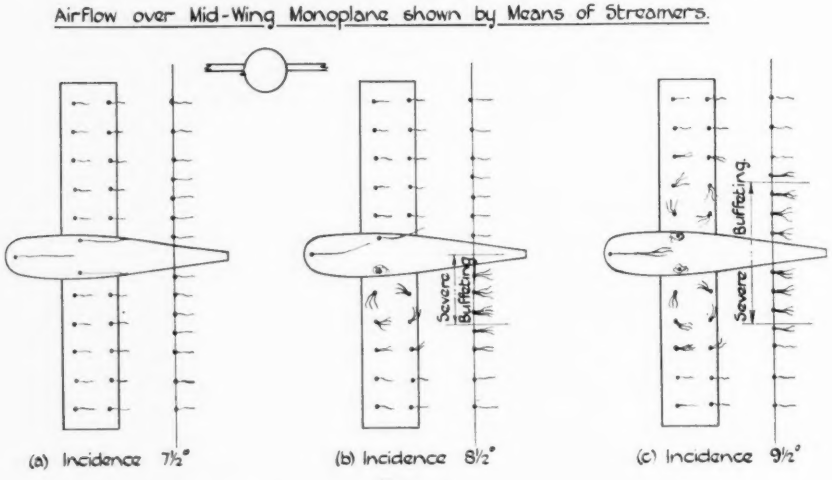


FIG. 10.

Fig. 10). At 8.5° the flow was always broken down in this region on one wing or the other, but never on both together, while at 9.5° the breakdown was continuous on both sides, but still confined to the same restricted area. When the incidence was further increased, the disturbance spread outward, and at 12° the wings were completely stalled except at the extreme tips.

Lastly, for the high-wing monoplane with circular body the flow was smooth for all incidences up to 11°. At 11.5° spasmodic breakdown began to occur on one or other of the wings, but never on both simultaneously. The flow continued to be rather erratic for incidences between 11.5° and 13°, but the breakdown of the flow occurred more frequently on the port wing, which is presumably due to some slight lack of symmetry in the model. After 13° the wings were completely stalled.

It will be seen that the high-wing monoplane shows to great advantage in these experiments.[12] This illustrates the principle that the stability of the flow is less sensitive to the presence of an obstruction (*i.e.*, the body) when it is placed

[11] In this experiment the model was of course firmly fixed. If it had been free as in flight, it seems possible that these spasms might have given rise to lateral instability, but on the other hand the freedom of the machine might have prevented their occurrence.

[12] But the other types can be greatly improved by the use of fairings, etc. (see below).

below the wings where the flow is convergent than when it is placed above the wings where the flow is divergent.

15. *Buffeting Tests of Wing-Body Combinations*

The number of tests made with wing-body combinations is large, and I shall content myself here with giving a few examples and a summary of results. Further details will be found in R. & M. 1541 (6).

As an example, take the low-wing monoplane with the body of D-shaped section. A series of measurements of the buffeting at a distance of two chords behind the trailing edge of the wings was made for five different wing incidences, and for a range of vertical positions of the detector. The results are summarised

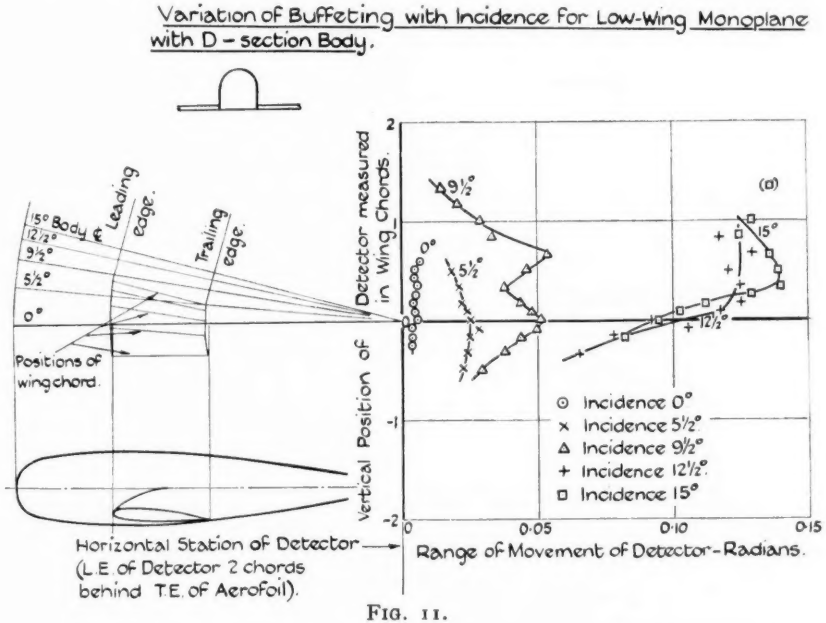


FIG. 11.

in the curves which appear on the right of Fig. 11. The ordinates of these curves give the vertical height of the detector above the centre line of the fuselage, and the abscissæ represent the range of the angular movement of the detector about its spring hinges. On the left of the figure are shown the projections upon a vertical plane of the centre line of the fuselage and of the wing chord for each of the incidences. This part of the diagram is drawn to the same scale as the ordinates of the curves on the right.

It will be seen that the intensity of the buffeting increases slowly and fairly regularly as the incidence increases from 0° up to 9.5°, but thereafter there is a sudden large increase corresponding to the stalling of the outer parts of the wings. For large incidences both above and below the stall the intensity of the buffeting decreases very rapidly as the detector is moved downwards. This illustrates the advantage from the standpoint of buffeting of placing the tailplane in the lowest possible position.

As a contrast to the above we may consider the results of the buffeting tests of the high-wing monoplane, which are shown in Fig. 12. It will be seen

that there is practically no buffeting for incidences below the stall, but that violent buffeting occurs above the stall within a certain region. However, a normally placed tailplane will be well below this region, so that even for incidences above the stall the buffeting will not be severe.

Fig. 13 provides a convenient comparison of the results obtained with the various wing-body combinations. The ordinate in this diagram is the greatest range of movement of the detector obtained in a traverse across the wake at a distance of two chords behind the trailing edge of the wings. It will be seen that the high-wing monoplane behaves very much like the wing alone, while the detrimental action of the body is greatest for the low-wing monoplane with circular body.

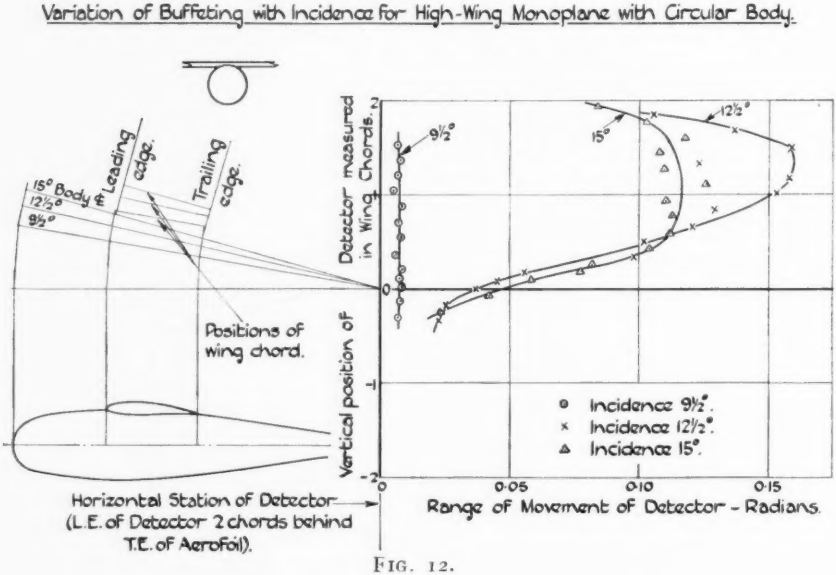


FIG. 12.

16. *Devices for the Prevention of Buffeting*

We have seen that the intensity of buffeting can be reduced by lowering the tailplane in relation to the wings. This expedient may be prohibited by other considerations, and a more radical cure must be sought. Now buffeting occurs, as we have seen, when the airflow over the wings breaks down, and we shall prevent buffeting in the most effective manner if we can prevent the breakdown of the flow. A brief consideration of the experiments on the wing-body combinations leads us to recognise that we have here to deal with two distinct problems which must be treated separately:—

(*a*) The prevention of premature stalling near the wing roots, such as occurs with low-wing and mid-wing monoplanes.

(*b*) The postponement of the stalling of the wings as a whole.

In the attempt to find practical solutions for these problems we must be guided by the principle that divergent flow is the usual cause of breakdown, and we must therefore adopt measures to counteract such divergence.

The best solution of problem (*a*) in the case of the low-wing monoplane is also the most obvious one, namely, the provision of fillets or fairings at the wing roots so proportioned that the divergence of the flow in this critical region is minimised. Fillets of this type have been used to improve the lift and drag characteristics of an aeroplane (12, 13), but, so far as I am aware, the first deliberate application of them to the prevention of buffeting is that described by C. Biechteler (15). Full-scale experiments were made on a low-wing monoplane of the B.F.W.-M. 23b type, and fillets of two different types were used. Fillet I consisted of a sheet metal fairing fitted into the angle between the wing and

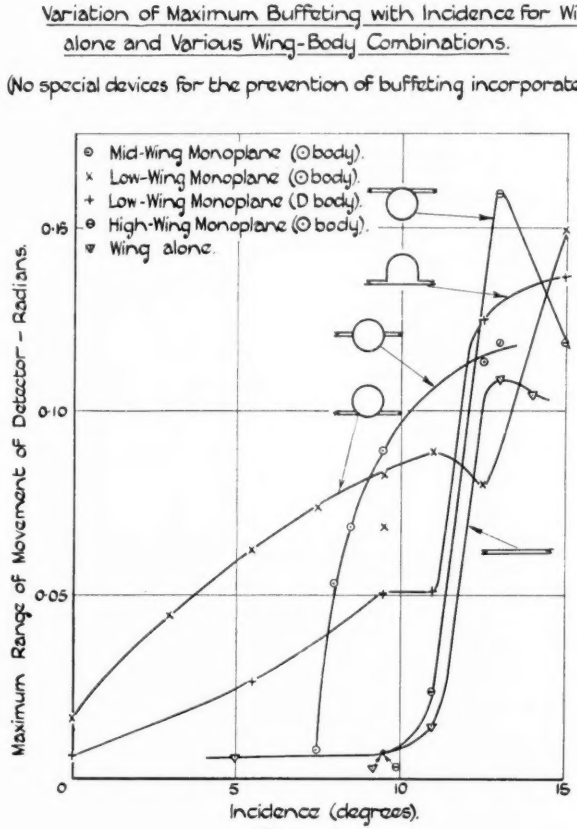


FIG. 13.

body, with a triangular extension carried backwards along the fuselage for some distance behind the trailing edge. The section of the fillet by a plane perpendicular to the longitudinal axis of the machine is a curve whose radius increases towards the rear. Fillet II was arranged similarly to fillet I, but for the sake of ease in manufacture the sheets of thin metal forming the surface were made as nearly flat as possible, so that the section of the fillet was triangular. These fairings were found to be very successful, as the only buffeting observed was slight and occurred when the aeroplane was sideslipping.

When we commenced our model experiments at the N.P.L. on the effects of wing-root fairings on buffeting, we were unaware of the German full-scale tests, but the fillets used by us were very similar to the German fillet I, and to the fillets used on several American low-wing monoplanes.[13] The specification (6) of the fillet tested by us is as follows:—" Within the wing chord the section of the fillet is a quadrant of a circle, whose radius increases linearly from zero at the leading edge to 1/3 chord at the trailing edge. The rear portion of the fillet is approximately triangular in plan, and extends 0.84 chord aft of the trailing

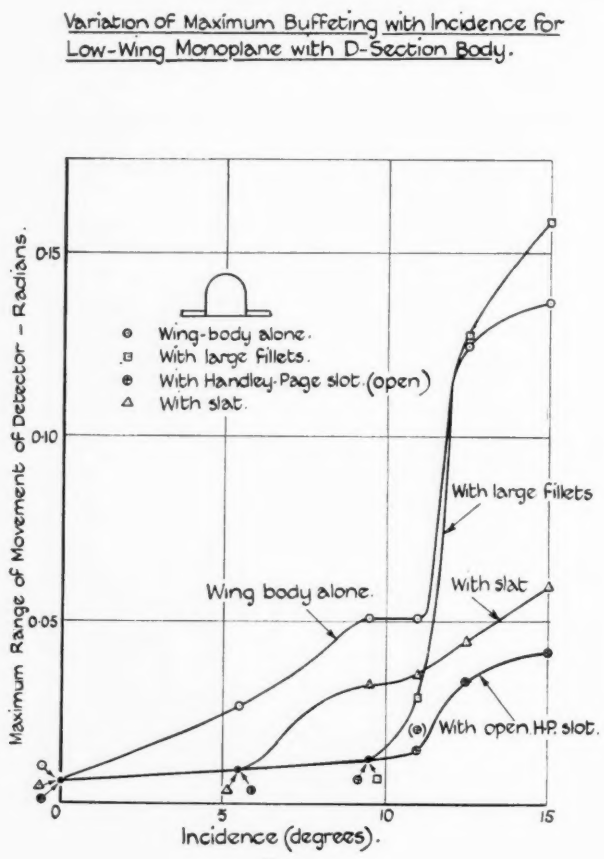


FIG. 14.

edge. The under surface of this rearward extension is a continuation of the under surface of the wing, and the upper surface is generated by circular arcs with radii diminishing towards the rear." Wing root fairings of this type were fitted to both of the low-wing combinations, and Fig. 14 provides a typical example of the results obtained. The tests appear to show that for all incidences below the stall and in the absence of sideslip, the buffeting characteristics of a

[13] These are of a type which research in many countries has shown to be very effective in the reduction of wing-body interference.

low-wing monoplane with suitable fillets may be about as good as for a high-wing monoplane. On the other hand, the fillets seem to be of no assistance at any incidence beyond the stalling angle; it is indeed clear that no root-fairing can serve to postpone breakdown of the flow except in the vicinity of the body.

An attempt was made to reduce the buffeting in the wake of the mid-wing monoplane with circular body by means of wing root fairings, but without success. It is probable that if the body had had an approximately rectangular section it would have been possible to correct the buffeting by means of fillets.

A very interesting series of tests on the influence of fillets on buffeting is described in N.A.C.A. Technical Note No. 460 (16). A McDonnell low-wing monoplane with and without wing root fairings and other special devices was tested in the N.A.C.A. full-scale wind tunnel. Severe tail buffeting occurred at large incidences when no devices for the prevention of buffeting were adopted,[14] but this was reduced to about 1/7 by the use of a large fairing at the wing root.

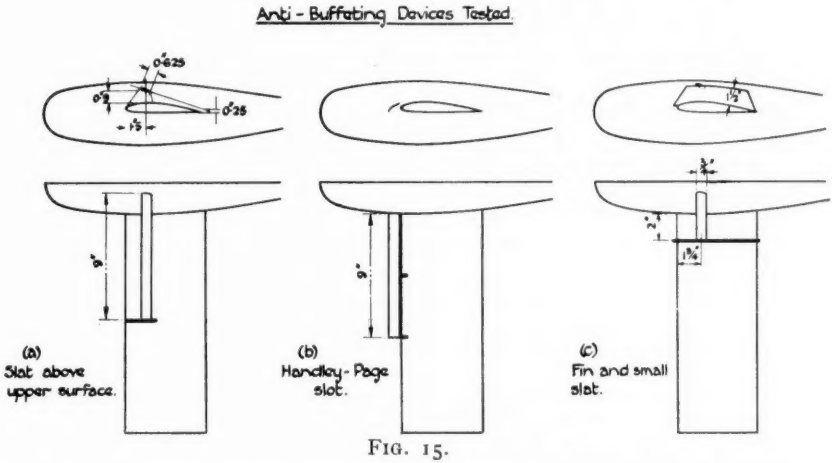


FIG. 15.

An N.A.C.A. engine cowling considerably assisted in the reduction of buffeting, but was not nearly so effective as the large fillet; moreover, when used with the fillet, it caused an actual increase of the buffeting. Tests were made with some small auxiliary aerofoils placed above the wings, but these were of little value in reducing the buffeting.

In addition to wing root fairings, three devices for the prevention of buffeting were tested in the N.P.L. experiments. These were (see Fig. 15):—

(1) A small fore-and-aft vertical fin on the upper surface of the wing near the wing root. In some tests the gap between the fin and the body was bridged by a small aerofoil.

(2) An auxiliary aerofoil or " slat " fixed above the wing.

(3) An open " slot " of the Handley Page type fitted at the leading edge.

[14] The range of movement of the tailplane tip was 1.5 inches under the following conditions:— Air speed 61 m.p.h., angle of incidence 16.1°, slipstream absent, rear end of fuselage externally supported. It is stated that the movements of the tailplane tip were almost doubled when the rear end of the fuselage was freed, although the movements of the rear end of the fuselage were only about ½ of those at the tailplane tip. Also the movements were rising steeply with wind speed within the range of speeds used. Hence it is probable that movements of the order of 3 or 4 inches could occur in flight during certain manœuvres. This is of the same order as the range of buffeting for the tailplane of a Junkers monoplane as deduced from model experiments. See Refs. 1 and 5.

The fin (1) was applied to the mid-wing monoplane only, but the slat and slot were tested on all the combinations.

The fin alone did not prevent premature breakdown of the flow at the wing root, but it did serve to confine the disturbance to the narrow space between itself and the body. Consequently the disturbed part of the wake was restricted to a narrow band which only impinged on the tailplane near its root, and therefore caused little buffeting. In a test at 9.5° incidence the presence of the fin reduced the buffeting by an amount ranging from 50 to 75 per cent. according to the position of the tailplane. The flow between the fin and body could easily be smoothed by fitting a small aerofoil across the gap,[15] but this only resulted in a small further reduction in the buffeting. As would be expected, the fin and small aerofoil were practically useless for incidences at or above the stalling angle of the wings.

The influence of the leading edge slot and of the " slat " on the buffeting of a low-wing monoplane is clearly shown in Fig. 14. Even above the stall and in the worst region of the wake the buffeting is not very severe when these devices are used. In the present instance the slat is decidedly inferior to the open slot at incidences below the stall, but this is not always so with other wing-body combinations. A serious objection to the slat is that if its incidence is such that it controls the buffeting successfully, then it adds largely to the drag of the aeroplane.[16] An automatic leading edge slot is free from this objection, but is then naturally quite ineffective below the stall. In order that a slot or slat may be efficient in preventing buffeting at the stall, it must extend from the body to a point on the wing distinctly outboard of the tailplane tip.

17. Quantitative Tests on Models of Specific Aircraft

The experiments on models hitherto described were designed to give general guidance only, and the results are not quantitatively applicable to any actual aircraft. It is, however, possible to obtain quantitative information from model experiments on buffeting, provided that aerodynamical scale effect is unimportant.[17]

When the model is *dynamically similar* to the full-scale aircraft, and when the conditions of test are suitably chosen,[18] then the ratio of the deflection of the tailplane to its span is the same for model and full-scale. The *strict* conditions for dynamical similarity of model and full-scale tests are as follows:—

(1) The model must be geometrically similar to the aircraft both externally and internally.

(2) The density of corresponding elements of the model and the aircraft must be in a constant ratio.

(3) The elasticities of corresponding elements must be in a constant ratio.

(4) The attitudes and modes of support must be similar.

(5) The scales of length, density, elasticity, and speed must be such that the ratios of corresponding forces are the same, whether these forces are of inertial, elastic, or aerodynamical origin.

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[15] A rather similar device has been used on a Monospar monoplane. Here a small aerofoil, whose angle of incidence could be varied at will, bridged the gap between the fuselage and an engine nacelle.

[16] The tests with the slat are by no means exhaustive, and it is quite possible that an arrangement which is satisfactory from all points of view could be found.

[17] Another factor which may have some influence is the degree of turbulence in the wind tunnel.

[18] The conditions for dynamical similarity were first stated by McKinnon Wood with applications to wing flutter in view, and he suggested the use of models of " reduced elasticity." An account of some quantitative buffeting tests on a model of a low-wing monoplane will be found in R. & M. 1457 (5).

Conditions (5) require symbols for their detailed statement. Let

l = a typical linear dimension (*e.g.*, wing chord);
σ = density of a typical element of the structure;
ϵ = a typical elastic restoring couple per radian of angular displacement;
V = air speed;
ν = kinematic viscosity of the air;
and ρ = air density.

Then the ratios of the several kinds of forces will be the same provided that the following three non-dimensional parameters have the same set of values for the model as for full-scale:—

$$\alpha = \sigma/\rho,$$
$$\beta = Vl/\nu,$$
$$\text{and } \gamma = \epsilon/\rho V^2 l^3.$$

Now it is not feasible to retain the full-scale values of all three parameters,[19] for this would require the air speed in the model test to be greater than for full-scale. If, however, the equality of the Reynolds numbers can be ignored, then the remaining conditions are easily satisfied, and the stiffness scale of the model can be chosen so that corresponding speeds for the model and the aircraft are in some convenient ratio. Conditions (1), (2), and (3) can be considerably relaxed. It is, of course, necessary that the model should be externally similar to the aircraft, but the structure can be greatly modified provided that what may be called the effective elasticities and mass distributions are not seriously affected. The question of the correct method of support for the model is more difficult, as the technique for taking measurements on a model flying in a wind tunnel has not yet been evolved. At the present time tests are usually made with the forward end of the model fuselage fixed, but it is not difficult to arrange for limited angular freedom of the fuselage in roll, pitch and yaw. In this way the conditions of flight can be fairly closely imitated.

Where the object in view is merely the improvement of the buffeting characteristics of an aeroplane and exact quantitative results are not required, it will usually be sufficient to use a rigid model with an elastically hinged tailplane. Much can in fact be done with a completely rigid model by the aid of wool streamers to indicate roughly the degree of unsteadiness of the airflow.

18. Concluding Remarks

Before closing this paper I shall refer to a few rather miscellaneous topics not hitherto mentioned. In the first place there is evidence both from flight tests (2) and model experiments (1) that sideslip may notably increase the severity of tail buffeting. Full-scale and model tests likewise agree in showing that the effect of the slipstream from the airscrew is usually to reduce the buffeting quite substantially (2, 5, 16). Unfortunately at the very time when buffeting most commonly occurs, namely, in landing, this beneficial agent is lacking.

So far as I am aware the earliest expedient proposed as a remedy for tail buffeting on low-wing monoplanes was reflexing the trailing edge of the wings in the region next the fuselage. Recent investigations both with models (5) and on an actual aeroplane (16) show, however, that reflexing has little beneficial effect and may even be detrimental.

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[19] Unless a tunnel using compressed air is available, so that ρ, and therefore also σ, has a higher value for the model test than for full-scale.

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Discussion

The Chairman: He would like to express his appreciation, not only of the lecture but of the enormous trouble which Dr. Duncan and Mr. Ellis had gone to in bringing a wind tunnel to the room. Having once been constructed, the apparatus would be extremely useful for other demonstrations and also for general experimental purposes at the Laboratory. In theory, the question of buffeting might be a serious one, although he felt it was fairly safe to say that in the majority of cases it was not very serious in practice, because usually the tail of an aeroplane was sufficiently stiff to prevent a forced oscillation from rising to any dangerous degree. Nevertheless, it was necessary to know about it and, in designing machines, to make the tails sufficiently stiff and put them in the place where they were least likely to be affected by buffeting; and at the same time to make wing-body combinations which would have the effect of reducing the possibility of danger from this cause. It was interesting to note that fillets applied to reduce buffeting are also likely to reduce drag, so that one design feature was in this case useful in two directions simultaneously.

Dr. Roxbee Cox, A.F.R.Ae.S.: He thought Dr. Duncan deserved their thanks twice over—firstly for the very comprehensive paper which he had prepared for publication, and secondly for the lecture which they had heard that night, and which included such an excellent demonstration of tail buffeting.

It was clear from the researches of Dr. Duncan and his colleagues, and of investigators abroad, that buffeting was to be expected when the wing of a monoplane was placed low relative to the tailplane. Their ignorance in this country of the phenomena of buffeting at the time of the Meopham accident was associated with their very limited experience of the low-wing monoplane. Now that this type of aeroplane was being built it was necessary to study Dr. Duncan's work very carefully if they were to avoid the buffeting troubles which had been experienced in Germany and America.

Although they had not yet the length of experience of the low-wing type which the Germans and Americans had, yet they had a good chance of avoiding the more serious troubles they had experienced for a reason which might be

worth noting. It was this: British pilots were in the habit of landing aeroplanes with the engines throttled back, which he (Dr. Roxbee Cox) believed was contrary to the practice in other countries. Now, as Dr. Duncan had pointed out, the airscrew slipstream contributed to the elimination of buffeting, and consequently an aeroplane which appeared satisfactory to a foreign pilot might exhibit signs of buffeting when being brought in to land by a British pilot. This was borne out by what two very experienced British pilots had told him. They had experienced very definite tail buffeting when landing certain foreign monoplanes which were then apparently regarded as satisfactory abroad. Now buffeting occurring when landing was unlikely to cause serious accident; it was a warning that serious accident might well occur if high incidence were inadvertently attained at high speed, when in spite of the moderating influence of the slipstream, the eddies from the wing were much more violent and frequent. The British habit of landing with engines throttled back, which tended to show up and not to hide any tendency to buffeting, may well be the cause of modifying an aeroplane which might otherwise have suffered catastrophe as the result of flying fast in gusty weather.

He had hoped that Dr. Duncan would have had something to say about biplanes. In the biplane the bottom wing was frequently lower, relative to the tail plane, than the wing of a low-wing monoplane. It might then be asked why they had had no experience of buffeting on biplanes. The answer presumably was that when a biplane as a whole stalled, the top wing was stalled but the bottom wing remained unstalled. But the bottom wing of a biplane might well become thoroughly stalled through the biplane encountering sufficiently vigorous up gusts. He suggested, therefore, especially as they tended to become bolder about flying in bad weather, that it should not be assumed that biplanes were essentially immune from buffeting, and that the stiffness of the tail of a biplane should be considered with as great care as the stiffness of the tail of a low-wing monoplane.

In this connection, Dr. Duncan stated that to be on the safe side the lowest natural frequency of the tail unit should not be less than twice the eddy frequency at the highest speed at which it appears possible for even momentary stall to occur. He would like to know whether this suggested rule was as much on the safe side as it appeared at first sight. In this connection, the natural frequency to which the author referred was presumably that measured on the ground. The natural frequency in flight of the tail unit would, on account of the increase in air damping, be less. He would like to know whether this effect was small and, if so, what other effects made Dr. Duncan propose to arrange for so large a difference between frequencies of the tail unit and the eddies. Was it inability to estimate the frequencies of the latter accurately?

Mr. A. G. Pugsley: There was one point on which he would like further information, and that was as to the effect of the torsional elasticity of the fuselage upon tail buffeting. It appeared to him that if, for example, one of the author's models had been placed at an angle of yaw in the demonstration tunnel, the eddies arising from one wing might well arrive at the tail out of phase with the eddies from the other wing, and so tend to produce torsional oscillations of the fuselage and tail unit. He would like the author's view as to whether serious oscillations of this nature were ever likely to occur in practice. It seemed to him that by varying the angle of yaw it should be possible to vary the frequencies and phase difference of the eddies concerned and so to vary the frequency of the torsional action on the tail, which might lead to torsional resonance at some critical values of wing incidence and yaw.

Dr. A. P. Thurston, F.R.Ae.S.: He suggested that drawings of the wind tunnel should be incorporated with the paper because the work that was being done in it was of a most ingenious and valuable character.

As regards buffeting, he had only known of one machine during the whole of the war in which the tail came off and in which there might have been a suspicion that it was due to buffeting. That, however, was a very early machine and the body was extremely narrow, although very deep. In other words, it was a body extremely weak in torsion. Had the author made any experiments, or did he propose to carry out any, on the torsional effect of buffeting, because, apart from the one case he had mentioned, he had seen no difficulty or danger during the war from tail buffeting? It would also be interesting to know if the author had tried rotary vanes on the tips of the wing, in view of their known efficacy and superiority over the slot.

Mr. S. CAMM, F.R.Ae.S.: With reference to the distance of the tailplane from the wing in the case of the biplane, this distance is usually much greater on the biplane than on the monoplane, and he did not know if this partly explained the difference in the behaviour of the two types of machines, from the point of view of buffeting.

The war-time case instanced by Dr. Thurston occurred while the pilot was carrying out a number of loops. From the ground it was observed that the tail unit was slightly damaged during the first loop, and finally broke off during the third loop. Although the fuselage may have been torsionally weak, he had the feeling that the failure was possibly due to weakness of a fitting, and not due to buffeting.

It was interesting to recall that the War Office placed a temporary ban on the monoplane in 1912 as a result of the number of accidents, and it did, at that time, appear that the monoplanes were more prone to trouble than the biplanes. He was not aware whether more monoplanes or biplanes were in use during the war, or whether there existed data giving the relative proportion of failures.

The author's experiments compelled one to come to the conclusion that the low-wing monoplane was inherently prone to this sort of trouble. The solution was obviously bound up with the question of relative stiffness of tail, fuselage and wings. Referring to the Meopham accident, he personally always thought that one of the wings failed first.

Mr. W. O. MANNING, F.R.Ae.S.: He would like to refer to the importance of the effect of propeller running on buffeting. Was there any difference between the amount of buffeting on one side of the fuselage and the other, due to this? He would expect, he said, that there would be some difference owing to the lack of symmetry of the propeller slipstream.

Another point of general interest was the region of maximum buffeting shown on the diagrams, and it would seem that if a low-wing monoplane was fitted with a biplane tail it would be possible to get 50 per cent. of the tailplane in the region where buffeting was comparatively small, and the effect would be to improve matters considerably.

One matter which the author had not touched upon, because it was not really within the scope of the paper, was the effect of buffeting on control at large angles of incidence. There was no question that when the tailplane was in a condition of violent turbulence, the control must be seriously affected.

Mr. A. HESSELL TILTMAN, F.R.Ae.S.: Had any researches been made upon the effect of twin propellers and buffeting on the tailplane? He was referring, he said, to the ordinary twin machine with two engines, one on either side of the fuselage.

Flight-Lieut. R. C. PRESTON, A.F.R.Ae.S.: In the final paragraph of the paper, it was stated that sideslip might notably increase the severity of tail buffeting. He asked for a little more information, because, having regard to Dr. Cox's suggestion that English pilots (contrary to Continental practice) were in the habit of bringing down their machines with the engines throttled back, it seemed to him that things were likely to be made worse by introducing a little sideslip, and serious disaster might follow. Flight-Lieut. Preston next referred

to an incident at Cranwell some time ago when the tailplane of a certain biplane developed a sort of flutter which was progressive right through the whole machine from elevator to nose. At the time the machine was coming to ground with the engine off, and he inquired whether Dr. Duncan, as the result of his recent researches, could say whether that was likely to be due to air buffeting in landing. Finally, he asked whether it was possible, in the apparatus the author exhibited, to demonstrate the results of sideslip.

R. A. FRAZER, F.R.Ae.S. (*communicated*) : His only active connection with the subject of buffeting goes back to some wind tunnel experiments carried out by Dr. Duncan and himself for the Accidents Investigation Sub-Committee in 1930. His remarks would therefore be restricted to those tests. They were carried out on a model Junkers monoplane of about one-ninth scale. The front fuselage and the wings were made rigid, but the tail unit was flexible and its stiffnesses were reduced in such a proportion that the speed scale for the model was one-tenth.

This model was originally designed and constructed, not for buffeting tests, but for the determination of the critical speed for tail flutter, and the result—so far as concerned flutter—was negative. The lowest measured critical speed corresponded to about 250 m.p.h. on full scale, whereas the highest speed expected in flight was, he thought, about 150 m.p.h. or less.

These flutter tests, which were carried out at normal incidences, included some in which air disturbances were artificially introduced into the tunnel, the object being to imitate the effects of gusts. And this was done by the simple expedient of waving a wooden rod, or wand, to and fro some distance upstream of the nose of the model. It so happened that on one occasion the wand was accidentally laid down on the upper surface of one of the wings in the region of maximum thickness. Immediately the tailplane became fiercely agitated. The term " buffeting " had already been used by others to describe an effect of this nature, and they adopted the word in reporting on the results. He believed that this incident marked the actual commencement of the general research which Dr. Duncan had so ably described and experimentally illustrated.

There is one specific question he would like to ask, and it is with reference to the recommendation that the lowest natural frequency of the tail unit should be not less than a certain eddy frequency. He would like to know whether, in the lecturer's opinion, the front fuselage can be treated as rigidly fixed in estimating the natural frequencies of the tail unit, and also whether any account should be taken of the aerodynamic stiffnesses and dampings of the tail organs?

REPLY TO DISCUSSION

He thanked Dr. Cox for his kind remarks about the lecture. He was interested to know of the different practice of British and Continental pilots as regards the throttling of the engine while landing, and agreed that the British practice of throttling right back would help to show up any tendency towards tail buffeting. With regard to tail buffeting on biplanes, there was as yet no experimental evidence so far as he knew. Certainly no experiments on the subject had yet been made at the National Physical Laboratory. He was inclined to agree with the explanation for the comparative immunity of biplanes from buffeting which had been suggested by Dr. Cox, namely, that the tailplane only received the wake of the lower wing, and that the lower wing normally stalled after the upper one. Dr. Cox had also spoken about the frequency criterion, but it was not pretended that this was anything more than a rough preliminary criterion. Before the Airworthiness Department would be able to lay down rules they would require to go into matters much more fully. Personally, he was of the opinion that the effect of air damping on frequency was comparatively small and not enough to worry about in a rough-and-ready criterion, but possibly later work would modify that view. The largeness of the suggested margin

between the natural frequencies of the tail unit and of the eddies, was intended to cover a " factor of ignorance " and also to ensure that the resonance amplification effect should be negligible.

Torsional elasticity of the fuselage had been mentioned by Mr. Pugsley, and although this had not been dealt with in detail in the paper, it had been mentioned in a footnote. Any torsional elasticity of the fuselage gave rise to a motion of the tailplane which was of the same general type as that due to flexure of the tailplane itself, and in such experiments as those dealt with in the paper it was not necessary to distinguish the one from the other. The part played by torsional elasticity was, of course, fully recognised, and in the early experiments on tail buffeting on a model of the Junkers monoplane which were made by Mr. Frazer and himself, the torsional stiffness of the fuselage was correctly represented. In some of the experiments the torsional motion of the fuselage was measured and found to be quite appreciable but not very important. The same question had been raised by other speakers, and therefore he need not refer to it again. As regards the influence of yaw, or sideslip, there was no doubt that this intensified the buffeting, but this was mainly, if not wholly, due to an actual increase in the intensity of the eddies. He agreed with Mr. Pugsley that the yaw of the machine would tend to produce a difference of phase between the aerodynamical impulses on the port and starboard tailplanes. It was, however, doubtful if this would influence the amplitude of the buffeting, since it was probable that there were random phase differences even in rectilinear flight without sideslip. He did not think that yaw would influence the effective eddy frequency in the manner suggested by Mr. Pugsley. Indeed, if the disturbances were sinusoidal, it was demonstrable that changes in the phase relations could not affect the frequency of the resultant forces and moments on the tail.

Dr. Thurston had mentioned the torsional effects of buffeting, but that had been replied to in connection with Mr. Pugsley's remarks. The case of failure mentioned by Dr. Thurston had been fairly well explained by Mr. Camm. So far, he himself had not tried the effect of rotary vanes, but possibly that might be done in the future.

One of the points mentioned by Mr. Camm as affecting the buffeting problem in biplanes was the distance of the tailplane behind the aerofoil. Of course, it was quite correct that the natural unit of measurement in this connection was the chord of the aerofoil. The chord of the biplane was admittedly smaller than for a monoplane of the same capacity, but all his experiments went to show that within the practicable range the distance of the tailplane behind the aerofoil was of no importance. Mr. Camm had expressed a very definite opinion about the Meopham accident, but, speaking officially, said the author, he had no opinion.

The effect of the running of the airscrew was mentioned by Mr. Manning, and it was suggested that it might possibly cause a difference of intensity of the buffeting on the two halves of the tailplane. That would certainly be expected, but he could only say that in the experiments on the model of the Junkers monoplane in which a running airscrew was used, no difference was detected in the intensity of the buffeting on the two sides. The effect, if any, would seem to be small. Personally, he did not think the biplane tail for low-wing monoplanes solved the problem. In any case, the lower plane of the biplane tail would have to be placed lower than the present tailplane, and he understood that that was precisely the thing which designers objected to for other reasons. Further, the upper plane would have to be a very long way above the lower one if it was to be kept free of trouble—at any rate for incidences at or above the stall—but below the stall something might be gained without excessive separation of the planes. The adverse influence of the wake on the controls at large angles of incidence was also mentioned by Mr. Manning, and that was certainly very important. However, this question was beyond the scope of the paper, and he would not discuss it further.

So far no experiments had been carried out on twin propellers—a matter mentioned by Mr. Tiltman. However, he saw no reason to suppose that the effect of the slipstream would be adverse. Flight-Lieut. Preston had mentioned sideslip and asked for more definite evidence on that point. As a matter of fact some definite results were quoted in R. and M. 1360. That was the Report on the Meopham accident, and in Appendix 21 there were given some definite results of the effect of yawing the model, which was equivalent to sideslip. Further, there was also quite a lot of full-scale evidence available. The D.V.L., in Germany, had made a very thorough investigation on the buffeting of a Junkers monoplane after the Report on the Meopham accident had been published, and among the experiments were some in which sideslip was deliberately induced. The buffeting was thereby markedly increased in severity. As regards the demonstration that evening, he regretted he was not able to yaw his models in the portable tunnel to show the effect of sideslip.

With regard to the communication from Mr. Frazer, he would like to add the comment that the experimenters at the N.P.L. made no claim whatever to have discovered buffeting. In fact, as had been stated in the paper, at the time of the Meopham accident it was already well known in Germany. In his opinion it would be sufficiently accurate to treat the forward part of the fuselage as rigid for the purpose of estimating the natural frequencies of the tail unit. He did not think that it would usually be necessary to take into account the aerodynamical stiffnesses and dampings of the tail organs when estimating the resonance frequencies.

Dr. Thurston asked if the name of the designer of the wind tunnel that had been exhibited could be given, because it was an extremely ingenious piece of apparatus.

The author replied that it was the result of a joint effort by Mr. Collar (who was also present), Mr. Ellis and himself.

THURSTON WING-TIP ROTORS

CONTROL BEYOND THE STALL

BY

A. P. THURSTON, D.SC., M.I.MECH.E., F.R.AE.S., M.I.A.E.

Summary and Deductions

The accompanying Report No. B.A. 1083 of the Royal Aircraft Establishment demonstrates generally that a moving body or rider plane can be associated with a fixed body or plane for altering the aerodynamic properties of the combination for various useful purposes, and in particular, that rotating cambered rider planes, when associated with the front edge of a fixed wing of standard section (see Fig. 11) " are definitely advantageous " in improving the gliding conditions, and that " by increasing the size of the rotors relatively to the size of the wings, this superiority is increased."

Previous experiments at the N.P.L. with various types of wings fitted alternately—with optimum wing-tip slots and with rotors—have shown that rotors can give about the same degree of lateral stability as tip slots, but over a much *wider angular range*. Other experiments with better rotors than used at the N.P.L. have shown that a more powerful stabilising effect over a wider annular range is to be obtained with rotors than with slots.

The report (B.A. 1083) further demonstrates that such rotors may be used (see Fig. 9) for controlling a machine laterally, directionally, and longitudinally, in addition to stabilising it. In other words, rotors may be used instead of—or in addition to—ailerons, rudders, or elevators. It follows that rotors may be associated with the trailing edges of a fixed wing for various purposes. It also follows that blades, or riders, if rotated about an external axis to sweep out " surfaces of revolution " may be used for reducing the head resistance and increasing the cooling of air-cooled engines mounted in the nose of an aeroplane body or the like. Obviously there are many other applications of this discovery awaiting development.

It may be remarked that if wing-tip rotors are considered in relationship to wing-tip slots, then rotor rings bear a similar relationship to Townend rings. If wing-tip rotors are regarded as " living " slots, then rotor rings may be similarly regarded as " living " cowling rings.

It should be remembered that Nature works with reciprocating mechanism, but that mechanism itself works best rotatively. Thus a wheel is more efficient than legs, an airscrew than flapping wings, and a wing-tip rotor than a reciprocating wing-tip slot.

Report B.A. 1083

The report represents six days' work in one wind tunnel at the Royal Aircraft Establishment. To carry out experiments involving 86 arrangements of

wings and rotors, 19 different arrangements of drag, besides numerous halts to make alterations to the mechanism or to construct new rotors, is not an indifferent achievement for six days' work. It must be allowed that this is a masterly demonstration of the value of the R.A.E. as a powerful engine of research.

The writer would like to take this opportunity of recording thanks to the authorities of the Air Ministry, and to the wind tunnel staff of the Royal Aircraft Establishment, Farnborough.

Method of Experiment

The method adopted in carrying out these experiments was as follows:—

The writer had an interview with the authorities of the Royal Aircraft Establishment and supplied them with sample rotors, leaving them to devise the fittings and supply a suitable plane and to carry out a few preliminary tests.

On arrival at Farnborough, two and a half days had already been spent in testing the fittings, making the preliminary runs, and so on. During these tests, one of the best pair of rotors had been broken. These set-backs are of course to be expected in all research.

The method of mounting the rotors devised by the Royal Aircraft Establishment was an entirely rigid one so as to ensure exact accuracy of the various angles of setting. In previous experiments it had been found best to make the axes of the rotors either laterally flexible or rockable, and, in some cases, the blades were transversely pivoted to the hubs. The spindle rods used by the Royal Aircraft Establishment were thick rods of crystal steel turned down at the end to a small diameter to form pintles for the blades with sharp re-entrant angles. The pintles were brittle and naturally weak at the root. Other pintles were formed from drawn wire brazed in holes drilled in the end of the spindle rods—these gave more satisfaction. Obviously, this trouble can be avoided either by making the pintles and hubs of larger diameter or by resiliently mounting the blades on the spindles.

After these preliminary troubles had been overcome, as there was no time to construct new fittings, the research was continued with reduced wind speeds and was directed to picking out the best shape of rotor from a number of constant diameter and various shapes. The results were worked out and plotted after each set of readings. The best rotor of all, namely, Port 33C, and the best pair of rotors, namely, Port 33C and Starboard 26A, were not found until within half an hour of the conclusion of these experiments. It is clear that if this pair had been used in the first experiments, this particular report would have been still more favourable than it is. It is also evident that there are still more suitable types of rotors and still more favourable positions awaiting development.

Best Rotors

The results of the readings taken with a pair of rotors, Port 33C and Starboard 26A, are shown plotted in the January issue of this Journal (Fig. 2, page 60), where K_L is plotted against inclination of the main plane. These rotors increase the lift coefficient K_L of a wing aspect ratio 4 from 0.416 to 0.716 at 25°, from 0.413 to 0.706 at 20°, from 0.46 to 0.675 at 15°, and from 0.368 to 0.545 at 10°; results, it may be remarked, unobtainable by slots at such angles of incidence.

Effect of Riders on Gliding Conditions

The report, in referring to the effect of rotors on gliding conditions, states that "The wings with rotor combinations are definitely advantageous," and

goes on to state that " by increasing the size of the rotors relatively to the size of the wing, this superiority is increased." It also states that " Tip slats have little effect on the angle of glide."

It is quite clear that the superiority of the rotor to the slot demonstrated by this report will be further increased by additional experiment as to shape, size and position of rotor.

Rotors for Control

Attention is directed to the possibility of using rotors for the purpose of controlling a machine in addition to stabilising it. Thus when the rotors are at position B′, namely, at the front corners of the wings, the lift and the drag at all angles of the main wing from 10° to 25° increase at an approximately constant rate with increase in inclination of the axis of rotation (see Fig. 9). Obviously, therefore, the rotors could be used in place of ailerons, rudders, or elevators. It is known that rider planes or slots can be used to give combined rolling and yawing moments of a most satisfactory combined nature for stabilising purposes, because, in certain positions of the rider plane, the drag of the combination is reduced. It is considered that a similar state of affairs will be found to hold in the case of rotors. At least it will be found that the resistance of the combination does not increase at the same rate as the lift, so that a machine with one wing down will tend to sweep round with the lower wing on the outside of the curve.

Methods of Carrying Rotors

There are many ways of carrying the rotors in flight. If they are used to replace ailerons and rudder, as well as to stabilise a machine, or act as an anti-stalling device, a good position appears to be the front corner of the wing; in this case the rotor could be allowed to rotate continuously. Its resistance is comparatively small when the machine is flying at a normal angle. If fitted to a high-speed machine the rotors can be nested on the front edge of the wing so as to offer no extra resistance, and means could be provided enabling them to be released from the cockpit when it is desired to land or fly slowly. The writer has made rotors which will automatically open and automatically close according to the inclination of the main plane. If it is only desired to use the rotors for landing, or to get a machine out of a spin, there is no need to make the rotors automatically closable, as this can be done after the machine is landed. During the course of his experimental work, the writer has been successful in constructing rotors which can be carried nesting on a section of the wing in line with the wind, which is a very satisfactory way of carrying rotors when on the extreme wing tips. The writer has also been successful in constructing rotors which would form " living " biplane or triplane slots when in rotation, and he has also constructed riders which would trail in the wind like a streamer flag until it was desired to bring them into rotation to form " living " slots or parachutes.

General Conclusions

After reading the report, it will be conceded that the discovery of rotors in conjunction with fixed wings has provided new means for controlling aircraft and preventing or controlling spinning, and also new means for securing slow landing and slow flying. In addition, the discovery has made possible a new type of aircraft combining an autogiro or helicopter in combination with a fixed wing machine. Other developments of this invention concern the cooling of aircraft engines and the reduction of head resistance.

REPORT No. B.A. 1083.
November, 1933.

ROYAL AIRCRAFT ESTABLISHMENT, FARNBOROUGH

WIND TUNNEL TEST OF A R.A.F.28 AEROFOIL WITH THURSTON ROTORS

BY

A. S. HARTSHORN, B.Sc., and C. CALLEN

A.M. Reference: 71687/30/R.D.A.3.
R.A.E. Reference: B.A./R.350/65.
Item No. 3G./8/33.

SUMMARY

Introductory (Purpose of Investigation)

These experiments were authorised to ascertain the effect of the Thurston rotors on lift and drag, and to compare the rates of descent at various gliding angles of wings with and without the rotors.

Range of Investigation

Lift was measured over an incidence range for 86 different arrangements of wing and rotors, and drag was measured for 19 different arrangements.

Conclusions

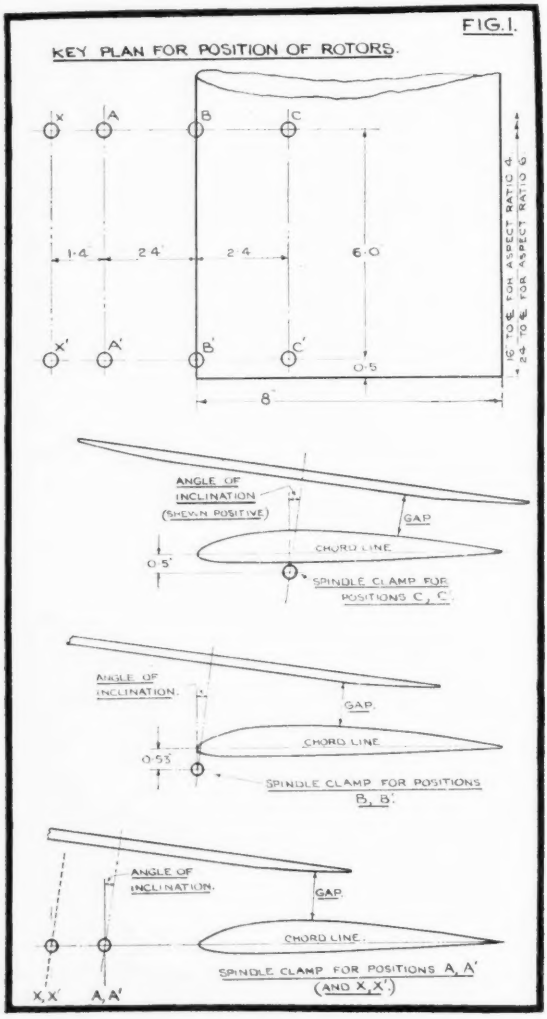
The maximum lift coefficient of the wing was increased from 0.47 at 15° incidence to 0.65 at 20° incidence by adding two rotors of diameter equal to one quarter the span, with the rotor axes 30 per cent. of the wing chord ahead of the wing tip. The gliding angle was increased about 25 per cent. for the same rate of descent. The increase in maximum lift coefficient decreased as the rotor was moved inboard or more over the wing. With the rotor axes on the leading edge of the wing and moved inboard so that the outer rotor tips were level with the wing tips the maximum lift coefficient was 0.58 at 20° incidence.

1. *Introduction*

The suggestion has been put forward by Dr. A. P. Thurston that the characteristics of a wing can be considerably improved by adding self-starting rotors at or near the wing tips. It is claimed that by placing these on each wing near the leading edge improvements analogous to those of a slotted wing tip can be obtained together with slow landing characteristics. Previous experiments (1) have shown that rotors can give about the same degree of lateral stability as tip slots. The primary object of these experiments was to test the second assertion, and the criterion by which this should be judged was that the gliding angle should be as steep as possible for a given rate of descent.

2. *Description of Model*

The shapes of the more successful rotors are given in Figs. 2-6. The rotors were supplied by Dr. Thurston and were made from strips of thin birchwood

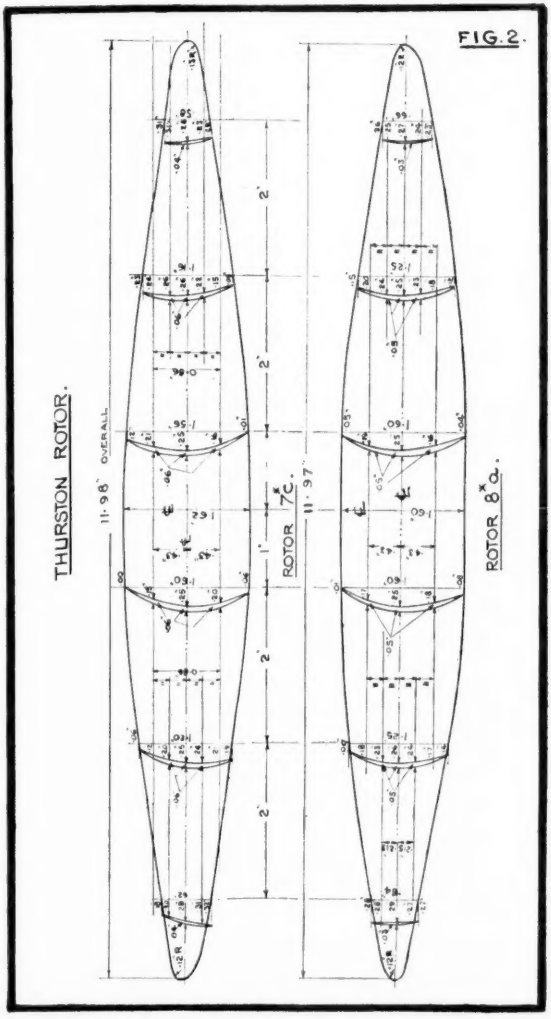


about 2 inches wide by 12 inches long. It is understood that these strips were damped and clamped round a circular cylinder until nearly dry and then moulded by hand to give a slight pitch. After painting with shellac to prevent further warping, the tips were shaped, the edges thinned down and the whole smoothed

off with sandpaper.* The rotors were mounted on a spindle so that they could rotate about an axis at right angles to the centre section chord.

The rotor spindles were attached to an 8in. by 48in. aerofoil of R.A.F. 28 section and the carrying brackets permitted the following variations:—

I. Distance of rotor from wing tip.
II. Distance of rotor from leading edge of aerofoil.
III. Inclination of spindle to wing chord.
IV. Clearance between rotor and upper surface of wing.

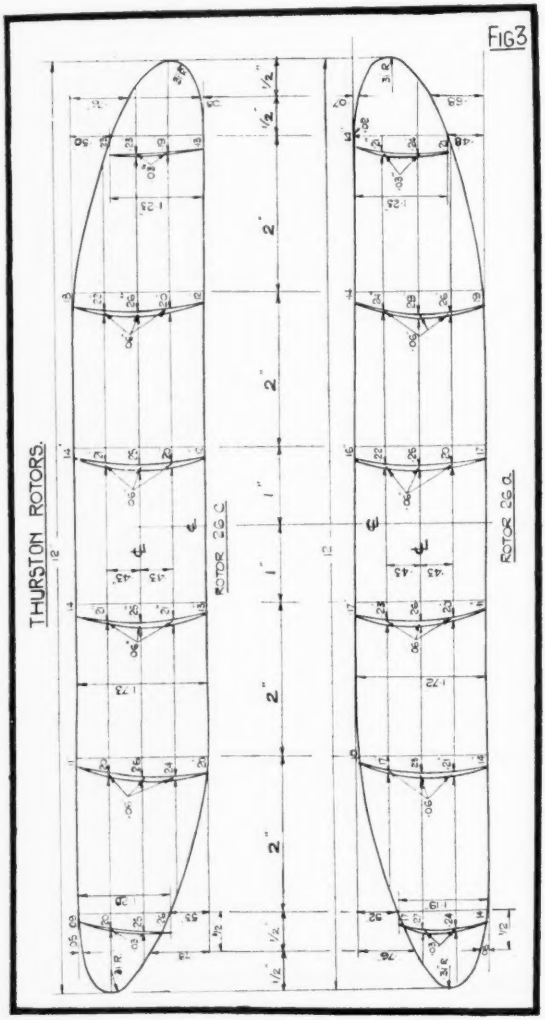


* These rotors were very flexible, particularly near the tip, and it is probable that they distorted under load. One of the wooden rotors (No. 29) was copied in brass, and the performance of the metal rotor was inferior to that of the original wooden one.

A few experiments were made with the aerofoil span cut down to 32in. (aspect ratio 4) the rotor dimensions being unaltered.

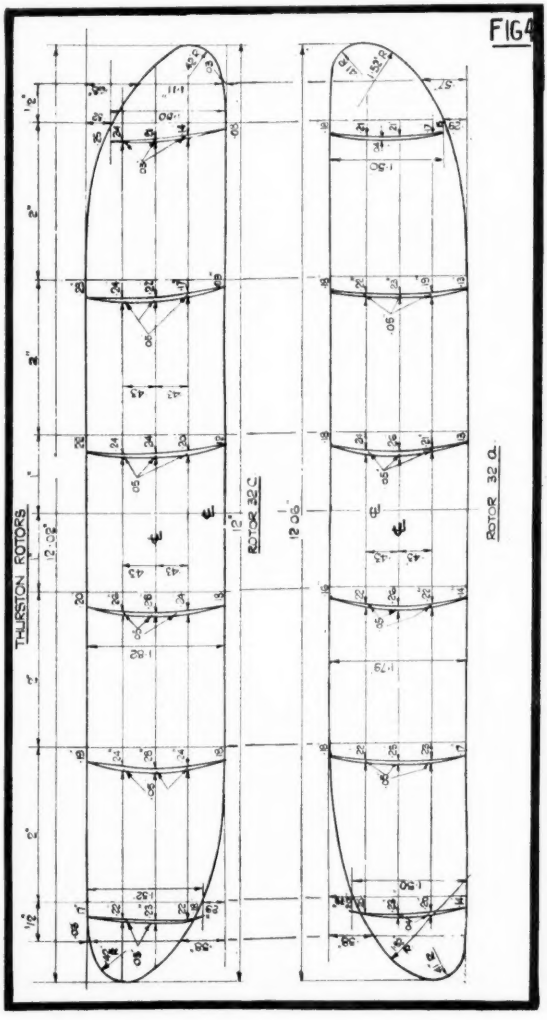
3. *Scheme of Tests*

The tests were made in the No. 1 seven-foot tunnel of the R.A.E. over a period of six days in October and November, 1933. For the first few tests the



wind speed was 60 ft./sec., but it was dropped to 50 ft./sec. and subsequently to 30 ft./sec. in order to prevent spindle breakage. Since the blades were not articulated, there were periodic bending moments which imposed severe reversing stresses on the spindles.

For the preliminary tests given in Table I, the lift only was measured over an incidence range from 10° to 25° in an attempt to find a rotor shape which gave a high lift in the neighbourhood of 15° to 20° incidence (*i.e.*, in the landing attitude). Measurements of drag were also made in the cases considered most

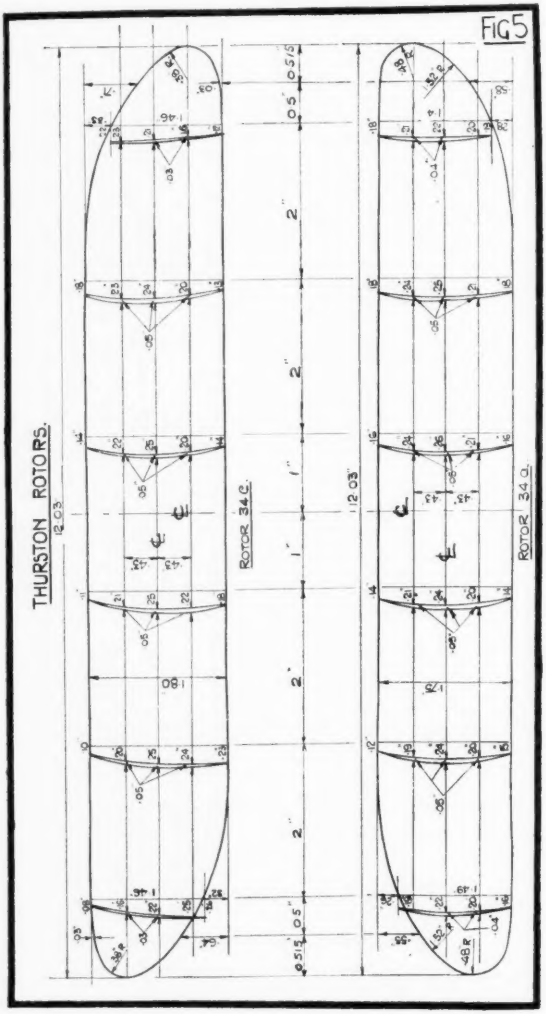


promising; these measurements, with the corresponding lift readings are given in Table II. In all cases, the particular combination tested was selected by Dr. Thurston who was present throughout the tests.

4. *Explanation of Tables*

A description of the particular combination tested is given under the heading

" Rotor details." The rotor shape is designated by a number and the direction of rotation by the letters " a " (anti-clockwise) and " c " (clockwise). Thus, " Star 8a " means that rotor No. 8 which rotates in an anti-clockwise direction when viewed from above was fixed to the starboard wing. Certain rotor numbers

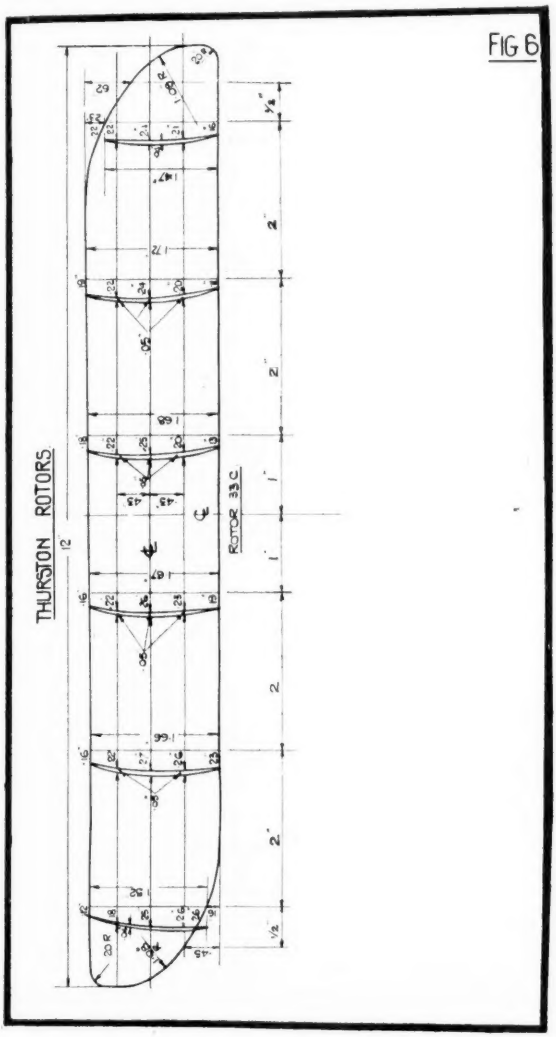


are marked with an asterisk. These were fashioned by Dr. Thurston to be copies of previous rotors of the same number, which had become damaged through spindle breakages.

The position in plan form is given by the letters A, A′, etc., in conjunction with the key plan given in Fig. 1. The angle given is the inclination of the rotor spindle to the normal to the wing chord and is positive when inclined backwards

(see Fig. 1). The length given is the minimum gap between the rotor and the upper surface of the aerofoil.

The wing incidences are recorded in the tables in the order of their measurement. The first tests were made with increasing incidence, but owing to the difficulty sometimes found in starting the rotor at low incidences the subsequent

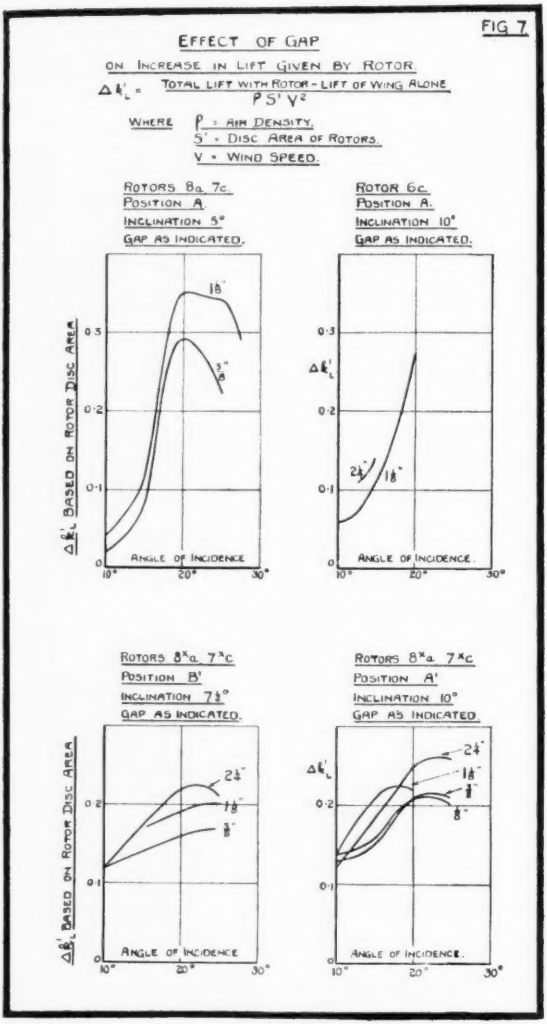


tests were made with decreasing incidences. The incidence given in the tables is the tunnel incidence and no correction has been made for tunnel constraint.

The total lift and drag of the combination is given in the form

$$k_L = \text{lift}/\rho S V^2$$
$$k_D = \text{drag}/\rho S V^2$$

where ρ is the density of the air,
S is the wing area (excluding rotors),
V is the wind velocity.

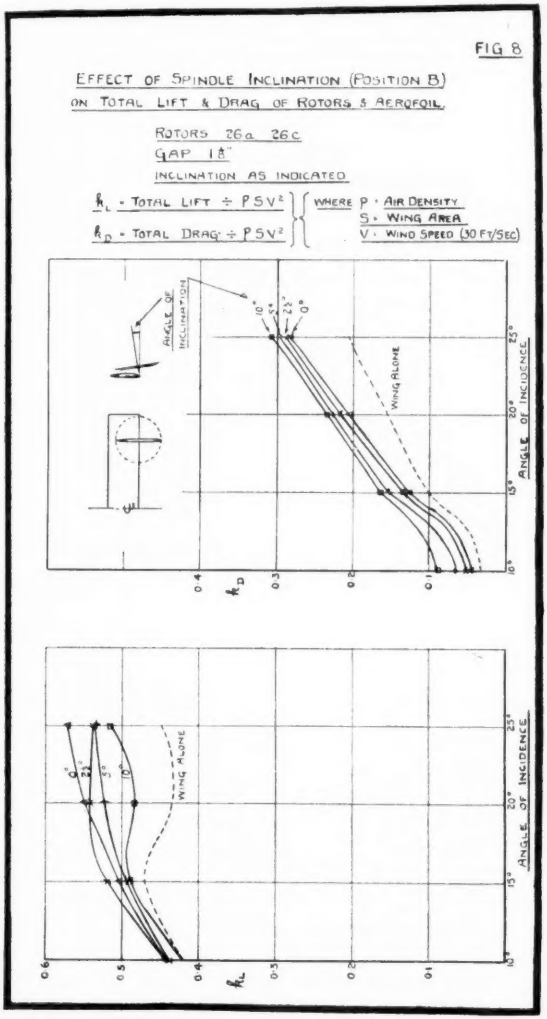


The difference between the force readings for the wing plus rotors and the wing alone is also given as a coefficient based on the disc area of the rotors,

$$\Delta k_L' = \Delta \text{ lift}/\rho S' V^2,$$
$$\Delta k_D' = \Delta \text{ drag}/\rho S' V^2,$$

where $S' = \pi/4$ sq. ft. for each rotor.

In a few cases, a single rotor was tested, and the lift coefficient k_L is for the wing plus one rotor. The coefficient $\Delta k_L'$ of the increase in lift due to the rotor in terms of rotor disc area should be comparable with the results for two rotors.

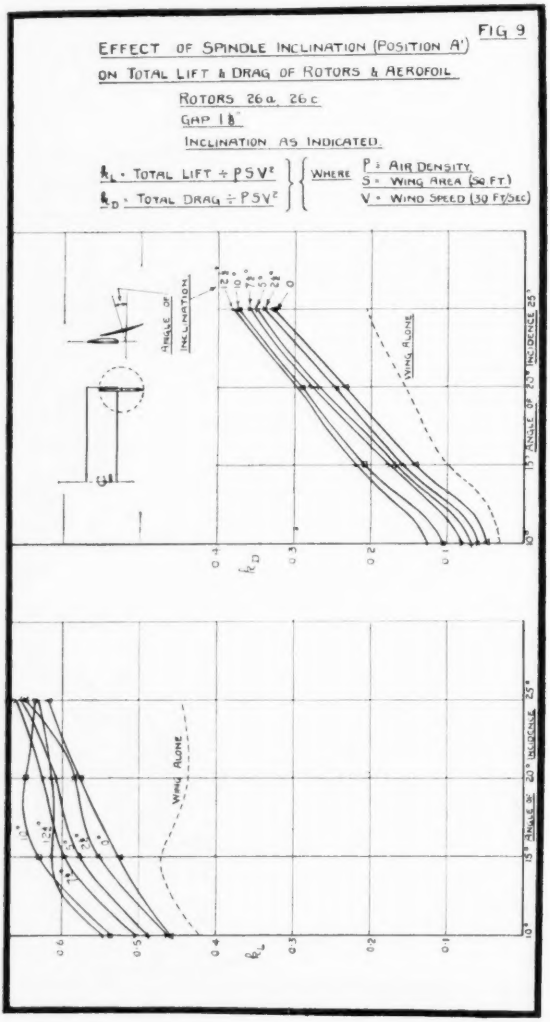


The further information given in Table II refers to the gliding flight characteristics of the wing alone.

If V = gliding speed,
W = total weight,
S = wing area,
ρ = air density,
$k_R = \sqrt{(k_L^2 + k_D^2)}$
γ = gliding angle = $\tan^{-1}(k_D/k_L)$.

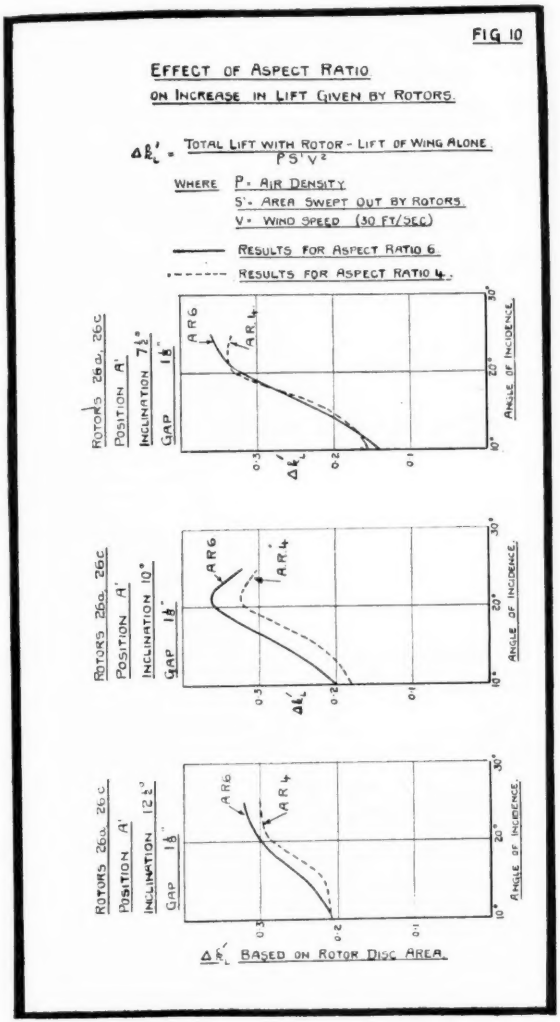
Then in a steady glide $W = k_R \rho S V^2$ and the vertical rate of descent is $V \sin \gamma = (k_D / k_R^{3/2}) \times \sqrt{(W/\rho S)}$.

In Table II $k_D/k_R^{3/2}$ and k_D/k_L are given, and these are plotted in Fig. 11, so that the ordinate is proportional to the rate of descent and the abscissa is the tangent of the gliding angle. An actual aeroplane will, of course, have an



additional drag due to fuselage struts and undercarriage and at low incidences the total drag is much greater than that of the wing alone. At and above the stall, however, the parasitic drag is small compared with the wing drag, so that deductions as to the merits of the rotors tested on the wing alone will apply with little change to the complete aircraft at angles of incidence of 15° and over. The

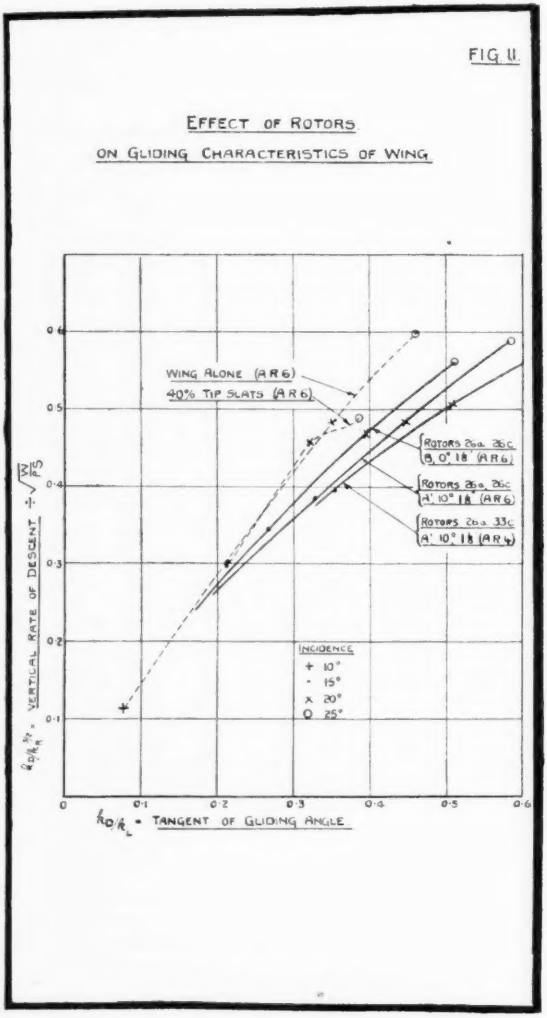
drag given in the tables includes that of the supports used. The additional drag caused by the model supports can be obtained from the tests of the wing alone and of the wing with brackets and spindles and its mean value is equivalent to a k_D of about 0.002.



5. *Results*

5.1. *Effect of Rotor Shape.*—In all, 28 different rotors were tested. An opposite handed pair was not always made, and when a single rotor only was made, it was sometimes tested with the opposite handed rotor from a pair whose lift was known.

In general it was found that camber was the most important variant, and rotors such as Nos. 26 and 33 (Figs. 3 and 6) with little camber were the most successful in giving a high lift in the region of 15° to 20° incidence where it was needed. The tests were not exhaustive enough to determine whether the optimum camber varied with rotor position.



5.2. *Effect of Gap* (*Fig.* 7).—The results are given in Fig. 7, in which the increase in lift due to adding rotors is expressed as a coefficient based on the disc area of the rotors. The effectiveness of the rotor seems to increase as the gap between rotor and wing increases. There does not appear to be any critical region, and the majority of the tests were confined to a gap of $1\frac{1}{8}$in.

5.3. *Effect of Inclination of Rotor Spindle.*—For rotors 26a, 26c, an inclination of about 10° is the optimum for position A′ (see Fig. 9) in front of the leading edge and an inclination of about $2\frac{1}{2}$° for position B on the leading edges (see Fig. 8). For rotors 8*a, 7*c, which have a greater camber than rotors 26a, 26c, the optimum inclination was found to be about $7\frac{1}{2}$° for position A′. These

SCHEDULE OF LIFT TESTS.

GAP	ANGLE OF INCLINATION TESTED (DEGREES)														
	$\frac{1}{8}$"	$\frac{3}{8}$"						1 $\frac{1}{8}$"					2 $\frac{1}{4}$"		
POSITION	A′	A	A′	B	B′	X	X′	A	A′	B	B′	C	C′	A	A′	B′
ROTOR																
4c								5								
6c								5								
								10	10					10		
7c				5												
								10								
7*c									7½							
8a		-5		-5												
		0														
		5														
11c								10								
20c								5								
21c								5								
22c								5								
23c								5								
24c								10	10				10			
6a. 6c									7½							
									10							
8a. 6c								10								
8a. 7c		-5								-5						
		0										0				
		5						5								
8*a. 7*c									0							
									2½							
									5		5					
					7½	7½	7½	7½	7½		7½		7½			7½
	10		10						10		10				10	
9c. 14c								5								
9c 10c								5								
								10								
8a STEEL R													2½			
													7½			
24a 24c									7½							
													10			
26a 26c									0+	0+						
									2½+	2½+						
									5+	5+						
									7½+							
							10		10+	10+						
									12½+							
									7½(4)							
									10(4)		10(4)					
									12½(4)							
26a. 14*c									10							
28a. 28c									7½							
29a. 29c											7½					
									10							
30a. 30c									7½							
32a. 32c										2½+						
										5+						
										7½+						
32a. 34c									10							
26a. 33c									10(4)+							
34a. 34c										2½+						
									10							

NOTE THE SIGN + SIGNIFIES THAT DRAG ALSO WAS MEASURED.
THE SIGN (4) INDICATES TEST ON ASPECT RATIO 4 WING

facts suggest that the optimum inclination depends both on the camber of the rotor and the intensity of the upwash in the area traversed by the rotor. The drag of the combinations, as shown in Figs. 8 and 9, increases with inclination in a fairly regular manner.

5.4. *Effect of Position.*—The tests show that within the range tested (*i.e.*, rotor axis 30 per cent. of wing chord behind leading edge to 47½ per cent. in front of it) the lift obtainable from the rotors increases as they are moved forward. The majority of the results were measured with the rotors in positions A and A′, *i.e.*, 30 per cent. of the chord ahead of the leading edge of the wing. As regards distance from the tip, higher lift coefficients were obtained with the rotor axis mounted at the tip than when mounted 6 inches in.

Figs. 8 and 9 illustrate the difference between the results at position B (axis at tip 0.3c forward) and at position A′ (axis 6 inches in, on leading edge).

5.5. *Effect of Aspect Ratio.*—A few tests were made with the wing cut down from aspect ratio 6 to aspect ratio 4, using the same size rotors. The lift coefficient based on the wing area alone will evidently be increased if the rotor gives the same increase for both wings. The actual increase in lift given by the rotors, expressed as a coefficient on rotor disc area, is shown in Fig. 10. It is seen that the effectiveness of the rotor in increasing the lift is on the whole less with an aspect ratio 4 wing than with an aspect ratio 6 wing.

5.6. *Direction of Rotation.*—In general, the rotor mounted on the starboard tip was shaped to revolve in an anti-clockwise direction when viewed from above, and the port rotor revolved in a clockwise direction. For one particular case (rotors 26a, 26c, position A′, inclination 10°, gap 1⅛in., aspect ratio 4) lift was measured with this direction of rotation and also with the rotors reversed. The lift was slightly greater with usual direction of rotation, *i.e.*, revolving so that the outer rotor blades moved against the wind and the inner rotor blades moved with the wind.

5.7. *Experimental Accuracy.*—The majority of the readings were taken with the wing in a stalled state. In certain cases there was a slow periodic increase and decrease in the lift. Where uncertainty occurred mean values were recorded and these are considered accurate to about 1 per cent.

6. *Effect of Rotors on Gliding Conditions*

Fig. 11 shows the vertical rate of descent plotted against the tangent of the angle of glide for the wing alone, the wing when fitted with 40 per cent. tip slats, and for the wing with the most effective rotors in positions A′ and B.

The criterion suggested in the introduction is that for a given rate of descent the angle of glide should be as steep as possible.

The wings with rotor combinations are definitely advantageous in this respect above 10° incidence (see Fig. 11). The merit of the various rotors is in the same order as that of the total lift coefficient of the rotor combination. Thus, position A′ is definitely superior to position B. By increasing the size of the rotors relative to the size of the wing (as shown by the aspect ratio 4 curve) this superiority is increased.

The tip slats have little effect on the angle of glide, as will of course be expected, since they are designed primarily to improve the stability characteristics only.

REFERENCE

No.	*Author.*	*Title, etc.*
1.	D. H. Williams, B.Sc.	S. & C. 456. Note on Thurston Riders, or rotating Alulas. May, 1932.

TABLE I.

LIFT RESULTS.

Aspect ratio 6. $V=60$ ft./sec.
α=degrees uncorrected for tunnel constraint.
k_L based on wing area.
k_L' based on disc area.

Rotor details.	α	k_L	$\Delta k_L'$	Rotor details.	α	k_L	$\Delta k_L'$
No rotors, brackets only	5	0.268	—	Star 7c	5	0.269	0
	7·5	0.357	—	Port —	7·5	0.342	−0.05
	10	0.430	—	Pos. B	10	0.415	−0.05
	12.5	0.477	—	Incl. +5°	12.5	0.457	−0.07
	15	0.482	—	Gap $\frac{3}{8}$in.	15	0.480	−0.01
	17·5	0.457	—		17.5	0.460	+0.01
	20	0.437	—				
		Aspect ratio 6.		$V=50$ ft./sec.			
No rotors, brackets only	5	0.272	—	Star 8a	—	—	—
	7·5	0.360	—	Port —	—	—	—
	10	0.428	—	Pos. A	10	0.436	0.03
	12.5	0.474	—	Incl. 0°	12.5	0.488	0.05
	15	0.485	—	Gap $\frac{3}{8}$in.	15	0.505	0.07
	17·5	0.443	—		17·5	0.505	0.21
	20	0.418	—		20	0.503	0.29
	22.5	0.430	—		22.5	0.529	0.34
	25	0.437	—		25	0.540	0.35
	27·5	0.440	—		27·5	0.543	0.35
	30	0.450	—		30	0.510	0.20
Star 8a	—	—	—	Star 8a	10	0.436	0.03
Port —	—	—	—	Port —	12.5	0.485	0.04
Pos. A	15	0.497	0.04	Pos. A	15	0.510	0.09
Incl. −5°	17·5	0.485	0.14	Incl. +5°	17·5	0.526	0.28
Gap $\frac{3}{8}$in.	20	0.463	0.15	Gap $\frac{3}{8}$in.	20	0.507	0.30
Star 8a	10	0.433	0.02	Star 8a	10	0.439	0.02
Port —	12½	0.483	0.03	Port 7c	15	0.526	0.07
Pos. B	15	0.492	0.02	Pos. A	20	0.570	0.26
Incl. −5°	17½	0.482	0.13	Incl. 0°	25	0.633	0.33
Gap $\frac{3}{8}$in.	—	—	—	Gap $\frac{3}{8}$in.	30	0.599	0.25
Star 8a	10	stops	--	Star 8a	10	0.437	0.02
Port 7c	12½	stops	—	Port 7c	12½	0.498	0.04
A	15	0.510	0.04	A	15	0.533	0.08
−5°	17½	0.510	0.11	+5°	17½	0.577	0.23
$\frac{3}{8}$in.	20	0.523	0.18	$\frac{3}{8}$in.	20	0.586	0.29
	22½	0.550	0.20		22½	0.587	0.27
	25	0.607	0.29		25	0.565	0.22
	27½	0.659	0.37				
	30	0.688	0.40				
Star 8a	10	0.453	0.04	Star 8a	10	No. 7 stops	
Port 7c	15	0.548	0.11	Port 7c	12½	0.489	0.03
A	20	0.623	0.35	B	15	0.502	0.03
+5°	22½	0.632	0.34	−5°	17½	0.503	0.10
1⅛in.	25	0.639	0.34	1⅛in.	20	0.528	0.19
	27½	0.610	0.29				

TABLE I (*continued*).

Rotor details.	α	k_L	$\Delta k_L'$	Rotor details.	α	k_L	$\Delta k_L'$
Star 8a	10	0.432	0.01	Star 20c	10	0.429	0
Port 7c	12½	0.478	0.01	Port —	12½	0.472	−0.01
C	15	0.491	0.01	A	15	0.490	0.02
0°	17½	0.490	0.08	+5°	17½	0.468	0.09
1⅛in.	20	0.495	0.13	1⅛in.	20	0.450	0.11
Star 21c	10	0.434	0.02	Star 22c	10	0.435	0.02
Port —	12½	0.485	0.04	Port —	12½	0.485	0.04
A	15	0.491	0.02	A	15	0.495	0.03
5°	17½	0.500	0.19	5°	17½	0.488	0.15
1⅛in.	20	0.466	0.16	1⅛in.	20	0.471	0.18
Star 23c	10	0.434	0.02	Star 6c	10	0.443	0.05
Port —	12½	0.482	0.03	Port —	12½	0.491	0.06
A	15	0.499	0.05	A	15	0.516	0.11
5°	17½	0.492	0.17	5°	17½	0.504	0.21
1⅛in.	20	0.477	0.20	1⅛in.	20	0.495	0.26
Star 4c	10	0.436	0.03	Star 8a	10	0.465	0.06
Port —	12½	0.482	0.03	Port 6c	12½	0.513	0.07
Pos. A	15	0.497	0.04	Pos. A	15	0.557	0.12
Incl. 5°	17½	0.492	0.17	Incl. 10°	20	0.578	0.27
Gap 1⅛in.	20	0.478	0.20	Gap 1⅛in.	—	—	—
Star 11c	10	0.435	0.02	Star —	10	0.446	0.06
Port —	12½	0.488	0.05	Port 6c	12½	0.495	0.07
A	15	0.495	0.03	A	15	0.518	0.11
10°	Rotor seized			10°	17½	0.496	0.18
1⅛in.				1⅛in.	20	0.498	0.27
Star —	10	0.447	0.06	Star —	—	—	—
Port 7c	12½	0.498	0.08	Port 6c	12½	0.507	0.11
A	15	0.522	0.13	A	15	0.526	0.14
+10°	17½	0.505	0.21	10°	—	—	—
1⅛in.	20	Spindle broke		2¼in.	—	—	—
Star 10c	10	0.449	0.04	Star 10c	10	0.447	0.03
Port 9c	12½	0.505	0.05	Port 9c	12½	0.503	0.05
A	15	0.536	0.09	A	15	0.517	0.05
10°	17½	0.532	0.15	5°	17½	0.521	0.13
1⅛in.	20	0.540	0.21	1⅛in.	20	0.548	0.22
Star 9c	10	0.444	0.03	Star —	10	0.456	0.10
Port 14c	12½	0.494	0.03	Port 6c	12½	0.508	0.12
A	15	0.518	0.06	A′	15	0.520	0.12
5°	17½	0.527	0.14	10°	17½	0.512	0.23
1⅛in.	20	0.525	0.18	1⅛in.	20	0.494	0.26
Star —	10	0.478	0.17	Star —	10	0.469	0.14
Port 24c	12½	0.525	0.17	Port 24c	12½	0.523	0.17
A′	15	0.548	0.21	C′	15	0.542	0.20
10°	17½	0.532	0.30	10°	17½	0.527	0.28
1⅛in.	20	0.517	0.34	1⅛in.	20	0.494	0.26

TABLE I (*continued*).

Rotor details.	α	k_L	$\Delta k_L'$	Rotor details.	α	k_L	$\Delta k_L'$
Star —	10	0.438	0.03				
Port 24c	12½	0.490	0.05				
A	15	0.519	0.12				
10°	17½	0.508	0.22				
1⅛in.	20	0.493	0.25				

Aspect ratio 6. $V=30$ ft./sec.

(measurements made in the order of decreasing incidences).

No rotors, brackets only	25	0.447	—	Star 8*a	25	0.565	0.20
	20	0.436	—	Port 7*c	20	0.565	0.22
	15	0.471	—	Pos. A′	15	0.593	0.21
	10	0.420	—	Incl. 10°	10	0.505	0.14
				Gap 1⅛in.	—	—	—
Star 8*a	25	0.600	0.26	Star 8*a	25	0.573	0.21
Port 7*c	20	0.580	0.25	Port 7*c	20	0.562	0.21
Pos. A′	15	0.577	0.18	A′	15	0.560	0.15
Incl. 10°	10	0.493	0.12	10°	10	0.498	0.13
Gap 2¼in.	—	—	—	⅜in.	—	—	—
Star 8*a	25	0.566	0.20	Star 8*a	25	0.601	0.26
Port 7*c	20	0.557	0.21	Port 7*c	20	0.585	0.25
A′	15	0.563	0.16	A′	15	0.593	0.21
10°	10	0.503	0.14	7½°	10	0.517	0.17
⅛in.	—	—	—	1⅛in.	—	—	—
Star 8*a	25	0.608	0.27	Star 8*a	25	0.608	0.27
Port 7*c	20	0.588	0.26	Port 7*c	20	0.582	0.25
A′	15	0.573	0.17	A′	15	0.578	0.18
5°	10	0.501	0.14	2½°	10	0.486	0.11
1⅛in.	—	—	—	1⅛in.	—	—	—
Star 8*a	25	0.603	0.27	Star —	25	0.501	0.18
Port 7*c	20	0.569	0.23	Port 7*c	20	0.475	0.13
A′	15	0.517	0.08	A′	15	0.498	0.09
0°	10	0.442	0.04	7½°	10	0.450	0.10
1⅛in.	—	—	—	1⅛in.	—	—	—
Star 8*a	25	0.627	0.31	Star 8*a	25	0.620	0.29
Port 7*c	20	0.605	0.29	Port 7*c	20	0.605	0.29
X′	15	0.593	0.21	X	15	0.582	0.19
7½°	10	0.517	0.17	7½°	10	0.473	0.09
1⅛in.	—	—	—	1⅛in.	—	—	—
Star 8*a	25	0.572	0.21	Star 8*a	25	0.534	0.15
Port 7*c	20	0.560	0.21	Port 7*c	20	0.548	0.19
Pos. A	15	0.547	0.13	Pos. C′	15	0.555	0.14
Incl. 7½°	10	0.470	0.09	Incl. 7½°	10	0.496	0.13
Gap 1⅛	—	—	—	Gap 1⅛	—	—	—

TABLE I (*continued*).

Rotor details.	α	k_L	$\Delta k_L'$
Star 8*a	25	0.562	0.20
Port 7*c	20	0.550	0.19
B′	15	0.569	0.17
$7\frac{1}{2}°$	10	0.517	0.17
$1\frac{1}{8}$in.	—	—	—
Star 8*a	25	0.552	0.18
Port 7*c	20	0.533	0.17
B′	15	0.559	0.15
10°	10	0.502	0.14
$1\frac{1}{8}$in.	—	—	—
Star 8*a	25	0.572	0.21
Port 7*c	20	0.566	0.22
B′	15	0.570	0.17
$7\frac{1}{2}°$	10	0.489	0.12
$2\frac{1}{4}$in.	—	—	—
Star —	25	0.498	0.17
Port 24c	20	0.500	0.22
C′	15	0.513	0.14
10°	10	0.485	0.22
$1\frac{1}{8}$in.	—	—	—
Star 29*a	25	0.522	0.13
Port 29c	20	0.493	0.10
B′	15	0.508	0.06
$7\frac{1}{2}°$	10	0.463	0.07
$1\frac{1}{8}$in.	—	—	—
Star 24*a	25	0.575	0.22
Port 24*c	20	0.550	0.19
A′	15	0.555	0.14
$7\frac{1}{2}°$	10	0.489	0.12
$1\frac{1}{8}$in.	—	—	—
Star 30a	25	0.557	0.19
Port 30c	20	0.518	0.14
Pos. A′	15	0.515	0.07
Incl. $7\frac{1}{2}°$	10	0.459	0.07
Gap $1\frac{1}{8}$in.	—	—	—
Star 6a	25	0.601	0.26
Port 6c	20	0.587	0.26
A′	15	0.587	0.20
10°	10	0.509	0.15
$1\frac{1}{8}$in.	—	—	—
Star 26a	25	0.637	0.32
Port 26c	20	0.641	0.35
X′	15	0.636	0.28
10°	10	0.547	0.22
$1\frac{1}{8}$in.	—	—	—

Rotor details.	α	k_L	$\Delta k_L'$
Star 8*a	25	0.542	0.16
Port 7*c	20	0.553	0.20
B′	15	0.553	0.14
5°	10	0.483	0.11
$1\frac{1}{8}$in.	—	—	—
Star 8*a	25	0.547	0.17
Port 7*c	20	0.532	0.16
B′	15	0.551	0.14
$7\frac{1}{2}°$	10	0.491	0.12
$\frac{3}{8}$in.	—	—	—
Star 24*a	25	0.526	0.13
Port 24*c	20	0.554	0.20
C′	15	0.543	0.12
10°	10	0.484	0.11
$1\frac{1}{8}$in.	—	—	—
Star 8*a	25	0.515	0.12
Port Steel Rc	20	0.509	0.12
C′	15	0.525	0.09
$7\frac{1}{2}°$	10	0.479	0.10
$1\frac{1}{8}$in.	—	—	—
Star 8*a	25	0.537	0.15
Port Steel Rc	20	0.510	0.13
C′	15	0.517	0.08
$2\frac{1}{2}°$	10	0.447	0.05
$1\frac{1}{8}$in.	—	—	—
Star 28a	25	0.559	0.19
Port 28c	20	0.512	0.13
A′	15	0.509	0.06
$7\frac{1}{2}°$	10	0.464	0.07
$1\frac{1}{8}$in.	—	—	—
Star 26a	25	0.628	0.31
Port 14*c	20	0.635	0.34
Pos. A′	15	0.600	0.22
Incl. 10°	10	0.533	0.19
Gap $1\frac{1}{8}$in.	—	—	—
Star 6a	25	0.605	0.27
Port 6c	20	0.580	0.24
A′	15	0.578	0.18
$7\frac{1}{2}°$	10	0.510	0.15
$1\frac{1}{8}$in.	—	—	—
Star 34a	25	0.647	0.34
Port 34c	20	0.617	0.31
A′	15	0.617	0.25
10°	10	0.543	0.21
$1\frac{1}{8}$in.	—	—	—

TABLE I (*continued*).

Rotor details.	α	k_L	$\Delta k_L'$	Rotor details.	α	k_L	$\Delta k_L'$
Star 29a	25	0.500	0.09	Star 32*a	25	0.650	0.35
Port 29c	20	0.489	0.09	Port 34c	20	0.628	0.33
A′	15	0.503	0.05	A′	15	0.627	0.27
10°	10	0.445	0.04	10°	—	Bracket broke	
$1\frac{1}{8}$in.	—	—	—	$1\frac{1}{8}$in.	—	—	—
		Aspect ratio 4 wing. $V=30$ ft./sec.					
No rotors	25	0.416	—	Star 26a	25	0.636	0.25
or	20	0.413	—	Port 26c	20	0.618	0.23
brackets	15	0.460	—	B′	15	0.592	0.15
	10	0.368	—	10°	10	0.476	0.12
				$1\frac{1}{8}$in.	—	—	—
Star 26a	25	0.677	0.30	Star 26c	25	0.668	0.29
Port 26c	20	0.698	0.32	Port 26a	20	0.684	0.31
A′	15	0.658	0.22	A′	15	0.647	0.21
10°	10	0.524	0.18	10°	10	0.529	0.18
$1\frac{1}{8}$in.	—	—	—	$1\frac{1}{8}$in.	—	—	—
Star 26a	25	0.707	0.33	Star 26a	25	0.680	0.30
Port 26c	20	0.700	0.33	Port 26c.	20	0.668	0.29
A′	15	0.637	0.20	A′	15	0.656	0.22
$7\frac{1}{2}$°	10	0.506	0.16	$12\frac{1}{2}$°	10	0.553	0.21
$1\frac{1}{8}$in.	—	—	—	$1\frac{1}{8}$in.	—	—	—

TABLE II.

COMBINED LIFT AND DRAG RESULTS.

α=degrees uncorrected for tunnel constraint.

k_L, k_D are based on wing area.

$\Delta k_L'$, $\Delta k_D'$ are based on disc area.

Aspect ratio 6. $V=30$ ft./sec.

Rotor details.	α	k_L	$\Delta k_L'$	k_D	$\Delta k_D'$	k_D/k_L	$k_D/k_R^{3/2}$
No	25	0.447	—	0.205	—	0.460	0.597
brackets	$22\frac{1}{2}$	—	—	0.198	—	—	—
or	20	0.436	—	0.154	—	0.353	0.485
rotors	$17\frac{1}{2}$	—	—	0.131	—	—	—
	15	0.471	—	0.101	—	0.215	0.302
	$12\frac{1}{2}$	—	—	0.049	—	—	—
	10	0.420	—	0.032	—	0.076	0.112
With	25	—	—	0.205	—	—	—
brackets	$22\frac{1}{2}$	—	—	0.183	—	—	—
and	20	—	—	0.160	—	—	—
spindles	$17\frac{1}{2}$	—	—	0.133	—	—	—
A, A′	15	—	—	0.102	—	—	—
X and X′	$12\frac{1}{2}$	—	—	0.049	—	—	—
	10	—	—	0.033	—	—	—

TABLE II (*continued*).

Rotor details.	a	k_L	$\Delta k_L'$	k_D	$\Delta k_D'$	k_D/k_L	$k_D/k_R^{3/2}$
With	25	—	—	0.206	—	—	—
brackets	20	—	—	0.156	—	—	—
and	15	—	—	0.103	—	—	—
spindles	10	—	—	0.033	—	—	—
B, B′	—	—	—	—	—	—	—
C and C′	—	—	—	—	—	—	—
Star 8*a	25	0.601	0.26	0.332	0.216	0.553	0.582
Port 7*c	20	0.585	0.25	0.260	0.180	0.445	0.510
Pos. A′	15	0.593	0.21	0.187	0.146	0.316	0.382
Incl. $7\frac{1}{2}°$	10	0.517	0.17	0.085	0.090	0.164	0.227
Gap $1\frac{1}{8}$in.	—	—	—	—	—	—	—
Star 26a	25	0.660	0.36	0.358	0.260	0.543	0.550
Port 26c	20	0.623	0.32	0.277	0.209	0.445	0.492
Pos. A′	15	0.596	0.21	0.177	0.129	0.297	0.359
Incl. $7\frac{1}{2}°$	10	0.500	0.14	0.079	0.080	0.157	0.217
Gap $1\frac{1}{8}$in.	—	—	—	—	—	—	—
Star 26a	25	0.636	0.32	0.372	0.284	0.585	0.589
Port 26c	20	0.647	0.36	0.290	0.231	0.448	0.483
A′	15	0.631	0.27	0.208	0.182	0.330	0.384
10°	10	0.535	0.20	0.104	0.122	0.194	0.257
$1\frac{1}{8}$in.	—	—	—	—	—	—	—
Star 26a	25	0.632	0.32	0.380	0.297	0.602	0.601
Port 26c	20	0.615	0.30	0.290	0.231	0.472	0.515
A′	15	0.612	0.24	0.217	0.197	0.355	0.410
$12\frac{1}{2}°$	10	0.542	0.21	0.125	0.158	0.231	0.300
$1\frac{1}{8}$in.	—	—	—	—	—	—	—
Star 26a	25	0.654	0.35	0.350	0.247	0.535	0.547
Port 26c	20	0.610	0.30	0.270	0.197	0.443	0.493
A′	15	0.578	0.18	0.168	0.114	0.290	0.357
5°	10	0.487	0.11	0.067	0.060	0.137	0.198
$1\frac{1}{8}$in.	—	—	—	—	—	—	—
Star 26a	25	0.647	0.34	0.341	0.231	0.527	0.541
Port 26c	20	0.584	0.25	0.245	0.155	0.420	0.485
A′	15	0.552	0.14	0.161	0.102	0.292	0.367
$2\frac{1}{2}°$	10	0.461	0.07	0.059	0.046	0.127	0.190
$1\frac{1}{8}$in.	—	—	—	—	—	—	—
Star 26a	25	0.620	0.29	0.327	0.207	0.527	0.553
Port 26c	20	0.577	0.24	0.233	0.134	0.404	0.468
A′	15	0.526	0.09	0.144	0.073	0.274	0.353
0°	10	0.459	0.07	0.048	0.027	0.104	0.155
$1\frac{1}{8}$in.	—	—	—	—	—	—	—
Star 26a	25	0.515	0.12	0.306	0.171	0.593	0.659
Port 26c	20	0.485	0.08	0.233	0.134	0.480	0.586
B	15	0.489	0.03	0.166	0.111	0.340	0.447
10°	10	0.419	0	0.093	0.104	0.222	0.328
$1\frac{1}{8}$in.	—	—	—	—	—	—	—

TABLE II (*continued*).

Rotor details.	α	k_L	$\Delta k_L'$	k_D	$\Delta k_D'$	k_D/k_L	$k_D/k_R^{3/2}$
Star 26a	25	0.535	0.15	0.293	0.149	0.547	0.608
Port 26c	20	0.524	0.15	0.227	0.124	0.433	0.525
Pos. B	15	0.491	0.03	0.152	0.087	0.310	0.410
Incl. 5°	10	0.438	0.03	0.064	0.054	0.146	0.221
Gap 1⅛in.	—	—	—	—	—	—	—
Star 32a	25	0.568	0.21	0.314	0.186	0.553	0.599
Port 32c	20	0.575	0.24	0.257	0.176	0.448	0.514
B	15	0.542	0.12	0.171	0.119	0.316	0.397
7½°	10	0.453	0.06	0.081	0.083	0.179	0.292
1⅛in.	—	—	—	—	—	—	—
Star 32a	25	0.593	0.25	0.305	0.170	0.515	0.562
Port 32c	20	0.577	0.24	0.247	0.158	0.429	0.494
B	15	0.526	0.09	0.158	0.097	0.300	0.385
5°	10	0.415	0	0.069	0.063	0.166	0.255
1⅛in.	—	—	—	—	—	—	—
Star 32a	25	0.600	0.26	0.301	0.163	0.501	0.547
Port 32c	20	0.568	0.22	0.233	0.134	0.411	0.483
B	15	0.517	0.08	0.141	0.068	0.273	0.357
2½°	10	0.442	0.04	0.055	0.039	0.123	0.188
1⅛in.	—	—	—	—	—	—	—
Star 34a	25	0.579	0.22	0.296	0.155	0.512	0.563
Port 34c	20	0.570	0.23	0.226	0.122	0.397	0.468
B	15	0.537	0.11	0.143	0.071	0.267	0.344
2½°	10	0.448	0.05	0.053	0.036	0.117	0.174
1⅛in.	—	—	—	—	—	—	—
Star 26a	25	0.537	0.15	0.290	0.144	0.540	0.605
Port 26c	20	0.542	0.18	0.216	0.105	0.399	0.483
B	15	0.520	0.08	0.132	0.053	0.254	0.333
2½°	10	0.438	0.03	0.051	0.032	0.115	0.178
1⅛in.	—	—	—	—	—	—	—
Star 26a	25	0.573	0.21	0.284	0.134	0.495	0.552
Port 26c	20	0.549	0.19	0.206	0.088	0.376	0.455
B	15	0.502	0.05	0.126	0.043	0.252	0.338
0°	10	0.442	0.04	0.046	0.024	0.103	0.154
1⅛in.	—	—	—	—	—	—	—
		Aspect ratio 4.		$V=30$ ft./sec.			
Star 26a	25	0.716	0.34	0.457	—	0.638	0.578
Port 33c	20	0.706	0.33	0.358	—	0.507	0.507
A′	15	0.675	0.24	0.239	—	0.355	0.391
10°	10	0.545	0.20	0.151	—	0.277	0.350
1⅛in.	—	—	—	—	—	—	—

ABSTRACTS OF PATENT SPECIFICATIONS

(*Specially abstracted for the Journal by W. O. Manning, F.R.Ae.S.*)

Regular abstracts of Patent Specifications received by the Society are published in the Journal. It should be noted that these abstracts are specially compiled by Mr. W. O. Manning, F.R.Ae.S., for the Journal and are only of those actually received and subsequently bound in volume form for reference in the library. These volumes extend from the earliest aeronautical patents to date, and form a unique collection of the efforts which have been made to conquer the air.

The Council accept no responsibility whatever for the accuracy of the abstracts and in any case of doubt the full patent can be consulted when necessary in the library of the Society.

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Aerodrome Equipment

402,632. *Improvements in or Relating to Landing Grounds for Aircraft.* Chevalier, J. P. L., 9, Rue Felicien David, Saint-Germain-la-Laye (Seine et Oise), France. Convention date (France), March 2nd, 1932.

The specification describes an arrangement of lighting for facilitating the landing of aircraft at night, or a similar arrangement may be used, substituting electric waves for the light, to facilitate landing in fog. The lighting arrangement consists of a number of light projectors in pairs, arranged on the line of approach of the aircraft, the beams from each pair of projectors being arranged to intersect. These intersections are arranged to occur at varying heights from the ground so that a pilot flying through the intersections is led on to the landing ground, which is illuminated normally. The light beams may be coloured, and a movable beam normally directed vertically is used to attract the attention of the aircraft pilot.

Aerofoils

402,514. *Improved High Lift Wing Section for Aeroplanes and the Like.* Read, R. G., 25, Croydon Road, Reigate, Surrey. Dated July 1st, 1932. No. 18,594.

The claim here is for a wing section on which the underside of the nose is formed with a hollow curve, this curve being faired into the remainder of the wing section, which is of normal shape.

Aeroplanes—Construction

402,236. *Improvements in Structural Members for Aircraft.* A.T.S. Company, Ltd., 5 and 6, Clement's Inn, Strand, London, W.C.2; and Dobson, R. H., "Ash Grove," Hollinwood, Lancs.; and Wylie, H. N., 5 and 6, Clement's Inn, Strand, London, W.C.2. Dated October 28th, 1932. No. 30,298.

This specification is concerned with a method of constructing sheet metal spars, struts, etc., for aircraft, the separate lengths of sheet metal with which

these structural members are built up being connected by electrical resistance welding. In order that this may be done, the parts are formed with outwardly projecting flanges which are used for the welding operation, some or all of the joints thus formed being afterwards pressed inward so that they are accommodated within the contour of the member. The parts may be subsequently heat-treated.

402,675. *Improvements in and Relating to Retractable Landing Gears for Aeroplanes and to Brakes for Use in Conjunction Therewith.* Minshall, R. J., and Boeing Airplane Co., both of 200, West Michigan Street, Seattle, County of King, State of Washington, U.S.A. Dated May 18th, 1933. No. 14,415.

This specification describes a retractable aeroplane chassis which is arranged so that landings can be made in emergency even if there is not time to move the landing wheels into the fully projected position, and in which the brake gear is arranged so that it may operate normally whatever the position of the chassis. The chassis described is of the type using three struts to each wheel, the vertical strut containing the shock-absorbing apparatus. The strut projecting rearwards is connected to a frame, one member of which is comprised by a threaded bar acting in a nut. On rotating this bar the chassis is caused to fold backwards into the wing, while the method of operation is irreversible so that landings can be made even if the chassis is partially folded. The brake device is operated mechanically, and linkage is arranged so that the operation of the brakes remains normal whatever the position of the chassis. It is stated that in certain emergencies, such as a forced landing on snow, it is safer to land with the chassis retracted so as to prevent the machine nosing over.

402,124. *Improvements in and Relating to Flotation or Buoyancy Boxes for Aircraft.* The British Thomson-Houston Co., Ltd., Crown House, Aldwych, London, W.C.2; Warren, H. W. H., "Lynn," St. Andrew's Road, Earlsdon, Coventry; Martin, R. I., 82, Eastland's Road, Rugby; Bray, G. R. R., 86, Dunchurch Road, Rugby. Dated May 25th, 1932. No. 14,888.

It is proposed to provide buoyancy for aircraft, which may land on the sea, by providing a flotation box composed of a number of water-tight boxes so shaped that when placed together they conform substantially to the curvature of the aeroplane wings. The boxes are constructed of varnished cloth or by sheets having surfaces of resin-bonded cloth, etc.

402,833. *Improvements in or Relating to Braking Systems for Aircraft.* Vickers (Aviation), Ltd., and Duncan, T. S., Weybridge Works, Byfleet Road, Weybridge, Surrey. Dated June 11th, 1933. No. 16,543.

This specification describes a method of arranging hydraulic brakes for aircraft, by which, without the use of a separate reservoir, it is possible to increase the brake pressure on the wheel or wheels on the inside of a turn, while at the same time reducing the brake pressure on the wheel on the outside of the turn. This augmentation of the pressure on the inside wheel is produced by pistons and cylinders operated by a cam attached to the rudder bar, there being one piston and cylinder for each side of the machine. Valve arrangements are described which make the operation of the device automatic, and the scheme is such that when the rudder bar is returned to neutral the augmented pressure is reduced to normal.

Aeroplanes—General

403,253. *Improvements in the Construction of Feathering Paddle Wheels, in particular for Aerodynamic Purposes.* Strandgren, C. B., 14, Rue Gallieni, Versailles (Seine et Oise), France. Convention dates (France), March 11th, 1932; January 25th, 1933.

This specification describes a method of constructing paddle wheels, or rotary lifters, for aircraft by means of which the various loads—aerodynamical, centrifugal, etc.—that act on the structure are opposed as far as possible by members in tension. Each paddle, for instance, is connected to the hub by flexible connecting members so that to each paddle corresponds another substantially aligned with it, each being attached to the hub at nearly the same place, hence relieving the hub of nearly all stress. Various arrangements for attaining this result are described.

403,157. *Improvements in Flying Machines.* McLaughlin, R. J., 73, West End Avenue, Manhattan Beach, Brooklyn, New York, U.S.A. Convention date (U.S.A.), August 17th, 1931.

This specification relates to the operation of wind wheels resembling buzz-saws. These wheels have hollow teeth which are intended to draw in air, which proceeds to the centre of the wheel, where it is compressed and driven downwards through vents. The reaction to this downward motion is stated to produce the lift. There is also a claim for a propeller with curved vanes extending from the axis to the circumference. The air is driven into a central compression space, where it reacts against the vanes and is driven backwards. Gear wheels fitted with spiral springs are also claimed. These allow the motors to start at full speed while the wind wheels slowly gather speed.

402,429. *Improvements in or Relating to Means for Propelling a Moving Body Through a Fluid Medium.* Mainguet, H., 10, Rue Garanciere, Paris, France. Convention date (France), June 1st, 1931.

This is a scheme for a type of rocket propulsion in which the high-speed gases are allowed to escape through an annular orifice formed by a gap between a streamline body and a streamline cap fitted on the nose on the body. The gases may be generated by the combustion of fuels or by the exhaust of an internal combustion engine. It is claimed that by this arrangement a vacuum is produced at the front of the body and a pressure at the rear, thereby augmenting the propulsion efficiency.

402,939. *Devices for Testing Aeroplanes and the Like.* Kosaburo Asano, 4 Itchome, Miyamoto-cho, Naka-Ku, Yokohama-shi Kanagawar-Ken, Japan. Dated December 12th, 1932. No. 35,243.

The device described is practically a whirling arm constructed on a large enough scale to enable it to deal with full-sized aircraft. The arm, or arms, carrying the aeroplane to be tested are fitted to a sort of cap on a tower, the cap being rotated electrically. Means are also provided so that the weight of the aeroplane can be balanced to any desired extent by pistons operated by compressed air within the tower, the arms being pivoted so that they can swing vertically, the inner ends of the arms being connected to the pistons.

402,992. *Aeroplane with Rotatable Wings.* De Chappedelaine, I. L. M. O., 51, Rue Chardon Lagache, Paris, France. Convention date (France), January 28th, 1933.

This specification refers to aeroplanes having rotatable wings, the section being of small curvature S form adapted to enter into autorotation under the action of air resistance. Arrangements are described whereby such aircraft may be

provided with locking devices enabling the wings to be fixed on the most favourable position for flight with fixed wings, or released for flight with rotating wings. The rotating wings may be driven by the engine. Means are provided whereby the pilot can give a differing inclination to the rotating wings.

Control of Aircraft

402,645. *Improvements in Aeroplane Rudders or the Like.* Avions, C. T. Weymann, 28, Rue Valentin, Levallois-Perret, Seine, France. Convention date, March 24th, 1932.

This specification refers to a type of air-brake for aeroplanes which consists of constructing the rudder in two halves, which normally remain in contact with each other but which can be opened up into the form of a V when an air-braking effect is required, and describes a method by which such a rudder may be operated. The rudder has normal control levers which are operated through a vertical shaft fitted in the fuselage also fitted with control levers. This latter shaft can be moved forward by the operation of another control so as to open the rudder to the form of a V.

402,941. *Improvements in or Relating to Means for Actuating Servo-Operating Controlling Surfaces for Aircraft and the Like.* The Fairey Aviation Co., Ltd., Cranford Lane, Hayes, Middlesex, and Williams, D. L. H., Hillside, Swakeley's Road, Ickenham, Middlesex, and Ordidge, F. H., Croft Gardens, Ruislip, Middlesex. Dated December 22nd, 1932. No. 36,329.

This specification refers to the method of servo-operation of controls which consists in providing a flap aft of the hinge axis of a control surface, the variable inclination of the flap being used to provide power for the operation of the control surfaces. The object of the device described being to obviate any risk of flutter by preventing transmission of energy to the control flap as a result of involuntary displacement of the main control surface. It is proposed, therefore, to use an arrangement by which there is no mechanical connection, over a limited range between the servo-flaps and the control surface. The arrangements shown are such as to maintain direct connection between the pilot's control and the flap, while providing for a limited degree of lost motion between this connection and the main control surface. Several mechanical devices are described by means of which this can be effected.

402,225. *Apparatus for the Automatic Operation of the Vertical and Traverse Stabilising of Aircraft.* Messgerate Boykiev, G.M.B.H., Goetz Allee, Zehlendorf, Berlin, Germany.

This specification refers to a method of automatic control of aircraft by which the ascertaining of the inclination of the aircraft about its axis is effected by means of nozzles or pitot heads, the differing pressures on these heads operating the controls. Sets of two nozzles are used, set at angles of 90°. Or the pressure differences shown by these nozzles may be made to operate an indicating device. The indicating device may carry a picture of a landscape, etc. Means are described by which the pressure differences in the nozzles may operate an electrical device which, in its turn, operates the controls.

401,266. *Aeroplane.* Mosimann, P., Utzenstorf, Bern, Switzerland. Dated March 7th, 1932. No. 6,814.

This specification relates to an aeroplane tail which is arranged to be rotatable round the fuselage on its longitudinal axis. The drawing shows an aeroplane, the rear part of the fuselage of which is rotatable on a steel tube fixed to the fuselage. This rear part carries an elevator. Both the rotatable portion and the elevator are under the control of the pilot.

401,580. *Improvements in Mechanism for Driving a Fan Propeller.* Wigger Meindersma, 167, Buurtweg, Wassemaar, The Hague, Holland. Dated April 7th, 1933. No. 10,485.

A fin propeller is a propeller consisting of a single blade which is caused to oscillate in such a manner as to propel. This specification describes a method of operating such propellers. The fin propeller being movable about a centre of oscillation and of the kind in which the axis of the propeller describes a conical path during half a revolution, the mechanism for driving consists of a coupling, one member being rotatable about an axis which is unsymmetrical with regard to the oscillating centre of the propeller, the other member of the coupling being slidable on the propeller arm. The two members of the coupling are also slidable with respect to each other, and movable with respect to each other in the manner of a hinge.

Pilots and Piloting

402,345. *Improvements in or Relating to Automatic Steering Apparatus for Air and other Craft.* Dehn, F. B., Kingsway House, 103, Kingsway, London, W.C.2. Dated May 19th, 1933. No. 14,579.

This specification describes an automatic pilot for aircraft, in which the steering is effected by the provision of a gyroscope having two degrees of freedom and adapted normally to precess about an axis at right angles, or having a component at right angles to that about which the steering is to be effected, the force exerted in the bearings of the precession axis acting directly or through relays on the control mechanism. These bearings may be resiliently mounted. The forces which control the steering may act on a pivoted jet tube discharging a fluid which oscillates under their action so that the fluid stream acts differentially on the two chambers of a fluid-pressure motor, which operates the rudder.

CORRESPONDENCE

To the Editor of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

Dear Sir,—Regarding the editorial notice on page 69 of the January issue of the "Journal of the Royal Aeronautical Society," I may give you the following notes concerning the first metal aeroplanes. Being unable to make use of verified references, I am compelled to refer here from memory and without giving exact dates, etc.

The first English metal aeroplane, and the first metal aeroplane in the world at all, was no doubt the aeroplane constructed by Sir Hiram Maxim (about 1896). Mr. Harry Harper shows clearly in his excellent book "The Steel Construction of Aeroplanes" (London, 1928) that Maxim had already used a steel tube framework. In the same book is also described how the steel construction has been developed in England by Mr. Mayo and others.

By no means can the Maxim aeroplane be called an *all-metal* aeroplane, but, taken from an engineering standpoint, a metal covering of wings or fuselages may certainly not be significant for metal construction (viz., the view of Dr. Dornier and his constructions).

The second English metal aeroplane was a curious biplane, designed about 1910 by an English officer, and built by Messrs. Accles and Pollock from drawn and properly bent steel tubes.

The first *all-metal* aeroplane in the world was certainly the curious pusher biplane designed by the late John Moisant and tested in France during 1910. This remarkable aeroplane showed very interesting principles of light metal construction. In 1911 the second all-metal aeroplane was built and exhibited in France. This was the " Tubavion " monoplane. The third all-metal aeroplane, and the first of its kind designed in Germany, was the very interesting monoplane of the engineer Dr. Frith Huth (not to be confused with Dr. Walther Huth, the founder of the German Albatros-Werke!). This was the first all-metal aeroplane really flown in the world. It was exhibited at the " Ala," 1912 (Berlin).

A very successful and interesting all-metal aeroplane was the " Ente " (" Canard "), designed by the famous German air pioneer Professor Hans Reissner at Aix-la-Chapelle during 1910-11. It was flown by the late Lucian Hild, and by the well-known Swiss engineer Mr. Robert Osell during 1912. The test flights shown at Johannisthal with this scientifically-designed tail-first monoplane were very remarkable. The wing of this aeroplane consisted of corrugated light metal (probably duralumin) sheets. It was tested by sand loading. At that time Professor Junkers collaborated with Mr. Reissner. Six years later Mr. Junkers succeeded in the application of this earlier experience in metal construction to his cantilever aeroplanes. But there were many laboratory experiments between the simple wing of the first Reissner " Ente " to the Junkers " J.4 " (Ju. D.I) constructed in 1917.

One of the first metal fuselages was possessed by the first " Nieuport " monoplane with uncovered fuselage tested by Mr. Edouard Nieuport (*recti* De Niéport), during 1909, near Paris. This fuselage consisted of conically drawn steel tubes welded together. Probably this was the first application of autogen welding in the aircraft industry. The design was due to the late Edouard Nieuport and to my friend Mr. Franz Schneider (who later constructed the L.V.G. aeroplanes of pre-war and war fame; also the inventor of the machine-gun gearing for shooting through the propeller, and also of the machine-gun turret—both designed during 1913-14). Welded steel parts were in the " Jatho " aeroplane of 1908-09, and the " Poulain " monoplanes of 1910.

Wing spars consisting of a single steel tube were used on the interesting " Bréguet " biplanes of pre-war time, the first being designed about 1910. This was also the first monospar wing.

Paulhan, the old collaborator of the famous Captain Ferber, built during 1911 a pusher biplane (or triplane?) showing an all-metal structure. In 1912 Professor Alexander Baumann designed a " Taube " monoplane with cantilever steel tube wings. It has never been tested. An interesting experimental aeroplane was the " Morane-Saulnier " metal monoplane exhibited at the Paris Salon of 1912. It had wing spars consisting of two steel tubes. The rounded fuselage showed partly a modern monocoque construction made from steel.

The first steel strip wing spars were patented by M. Esnault-Pelterie or Messrs. Clement-Bayard during 1911. Also, Mr. Chillingworth, of Nurnberg, experimented and delivered pressed steel sheet spars for wings and fuselages (1911).

The first steel strip wing spars were systematically designed and tested by Mr. Claude Dornier during 1914-15. Dr. Dornier got nearly the same results as the English experiments beginning in 1916. But for cheap and quick production he preferred more simple forms than the corrugated steel strip experimented with. In the Dornier Museum at Friedrichshafen one may see such early steel strip spars. They resemble closely the wing spars of modern English design.

Perhaps it may be of interest to your readers to hear that the first mention of the possibility of constructing aeroplanes from stainless steel may be found in your Journal during 1914!

Very truly yours,

A. R. Weyl.

REVIEW

Behind the Smoke Screen

Brig.-General P. R. C. Groves, C.B., C.M.G., D.S.O. Faber and Faber. 15/- net.

There were many in the past, and there will be many more in the future, who will do their best to discredit Brig.-General Groves. "Oh, that mine enemy had written a book." Here is the book and it will be heralded with very varying feelings by all who read it. It is a book, however, which has got to be read and one which ultimately will take an important place in aeronautical literature. Whatever accusations may be made against General Groves, there are two which certainly never can be made. One is that he is not an enthusiast on air matters, and the other is that he has not courage. He attacks remorselessly the higher command by name, and presents a case which is damning for those who still are British minded and not internationally minded. Whatever may be said in favour of peace or war, there is not the slightest doubt that in the counsels of the world the British Empire, and in particular Great Britain, does not count in the way that it did 20 years ago. The basis of the whole argument of Brig.-General Groves's book is that if you wish to be strong to keep the peace of the world you must be strong in the arm. That, in effect, might is right. The present reviewer subscribes very fully to this dogma because he has yet to find any definition of right which does not ultimately depend upon force. Force does not mean in the ultimate end of things, armaments in any shape or form. The power of one mind over another can be more terrible than the power exercised by bombing aircraft over the most helpless savages. Even the most peace-loving peoples in the world wish to impose their doctrines upon the rest of the world, and what does impose mean in the ultimate but force? "Behind the Smoke Screen" is a powerful indictment and one which should be read by everyone who wishes to see the peace of the world kept. There is no doubt—whether General Groves be right or wrong—that the air position in this country is not as it should be; that if one quarter of the proposals put forward by the committee under the chairmanship of the greatest airminded man this country has ever known, the late Lord Northcliffe, had been carried out, we should now have nothing about which to worry. The position of the affairs at the present day in the air is due, not so much to the apathy of the British public but to the intrigues of those who are in the air. Too many are thinking of themselves and not of the State, but the abolition of petty personal interests is as far off as the abolition of war. Brig.-General Groves has made the direct attack on the most powerful bureaucracy in the world, and one is only afraid that the lance of the modern Don Quixote will be shattered against the windmills of self-interest which are so effectively hidden behind the smoke screen.

The 570th Lecture read before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

Fifth Meeting, First Half, 69th Session

The Fifth Meeting of the 69th Session of the Royal Aeronautical Society was held on Thursday, 7th December, 1933, at 6.30 p.m., in the Lecture Hall of the Royal Society of Arts, 18, John Street, Adelphi, W.C.2. In the chair, the President, Mr. C. R. Fairey, M.B.E., F.R.Ae.S.

The Chairman: The Society had entertained many famous men, but he knew of no lecturer whom he had greater pleasure in introducing. The subject of the lecture was one of perennial interest. The controversy was still going on and that night they were to hear, as the protagonist of the air-cooled engine, the one man in this country, if not in the whole world, who could be acclaimed as the leading authority. When Mr. Fedden took up that particular branch of work after the war, he took up a type of motor which was rather under a cloud. He showed himself a bold experimenter and innovator, and it was unnecessary to recite what brilliant success he had achieved. They were all aware that he was the Chief Engineer of the Bristol Aeroplane Company, and no lecturer less needed an introduction to that meeting.

POSSIBLE FUTURE DEVELOPMENTS OF AIR-COOLED AERO ENGINES

BY

A. H. R. FEDDEN, M.B.E., F.R.Ae.S., M.I.A.E., M.I.M.E., M.S.A.E.

Section I.

General Introduction

The title chosen for this paper is a somewhat ambitious one, as prophecies in any sphere of engineering are always dangerous. Especially is this so in such a young and progressive branch as aeronautics, where changes are rapid, and developments considered modern and up-to-date to-day, may, in a few years, be thrown aside as being obsolete. However, when I received the honour of an invitation to read a paper before the Royal Aeronautical Society, I chose this title with "malice aforethought," if only with the idea of inviting criticism and discussion.

At the outset, I should like to make it quite clear that I lay no special claims to the gift of prophecy—rather do I approach this subject with the feeling that, at the present time, it is highly desirable to ascertain what should be aimed at for the future, and to submit to you certain suggestions as to how these requirements may be met.

Although you may not agree with some of the proposals, I hope, however, that I shall have attained my main object, namely, to have put before you certain aspects of air-cooled aero engine design which may provide subject matter for discussion.

In reviewing the possible future development of aircraft engines, I propose to confine myself to air-cooled engines for the immediate future—what we may expect during the next ten to fifteen years—as being the most profitable subject for discussion. I do not propose to attempt to consider power plants which are remotely conceivable for aircraft—such hardy annuals as petrol turbines, rocket propulsion, swash-plate engines, etc., as such schemes are so widely diversified, and cover such a large and speculative field, that it would be hardly feasible to investigate them in detail, in the short space of time available. As a matter of passing interest, however, it is worthy of mention that this question of conceivable and inconceivable power plants for aircraft is always a subject of considerable " grief and pain " to my colleagues and myself.

The investigation of new ideas is really a difficult question, and takes up a great deal of time, as it is always dangerous to pass over any design unheeded, as something may be missed which might be profitable in later years. However, you may rest assured that I am not going to explore the realms of phantasy, but will endeavour to adhere to concrete facts, and deal with the aircraft power plant as typified by the internal combustion engine of to-day.

Naturally, being connected with a firm producing air-cooled aero engines only, my activities are directed into the exploration of the air-cooled engine field, and in endeavouring to find as many openings as possible for the employment of direct air-cooled power plant for aircraft.

During the period which we are going to review this evening, I do not think that liquid or direct air cooling will either completely supplant the other for aircraft power plants, but that each will have its own particular application. Each type will inevitably undergo a considerable amount of modification, but I submit that if the trend of development is along the lines suggested, the use of direct air cooling will increase and its scope be widened, while liquid cooling technique may be concentrated on specialised types of aircraft.

I believe there is a great deal of important and interesting work that will be accomplished during this period, but I suggest that it will be more along the lines of development rather than any radical change, and I hope that you will not think I am too conservative in my opinions.

The piston, connecting rod, and crankshaft, may appear to provide a somewhat cumbersome arrangement, but this combination has stood the test of time remarkably well, and, in my opinion, will still be with us during the period under review.

I propose to confine most of my remarks to the four-cycle engine, as I am of the opinion that this type of engine is most likely to predominate during the period considered.

The two-stroke engine has come forward, from time to time, as an attractive line of development for aircraft engines, but I have never been very hopeful of it, and doubt if it will prove a profitable solution, at any rate for direct air cooling at high speeds, as it has to clear out the exhaust gases and take in a fresh charge in about a fifth of the time available for the four-stroke. Possibly, with direct petrol injection combined with supercharging it may prove successful, and it may also be the ultimate solution for the compression-ignition or Diesel engine, but I will refer to these points in greater detail later on in the paper.

Section II.

Review of the Present Air-cooled Aero Engine Situation

At this stage it may be useful to review, shortly, the present position of the air-cooled aero engine, and the change of policy that has taken place in regard to this type in Europe and America.

During the first year or two of the late European War, we find that air-cooled engines of from 80 to 150 h.p. were employed in considerable numbers, the major

portion being of the rotary type. We then find that the call for higher powers could not be met by the rotary engine and existing air-cooling technique, with the result that, for the remaining period of the war, both the Allies and Germany relied, almost exclusively, on in-line water-cooled engines. At the cessation of hostilities, in the autumn of 1918, the six-cylinder in-line and the " V " in-line water-cooled engines of 250-300 h.p. were supreme, although, just before the end of the war, it had been planned by the Royal Air Force to change over a considerable portion of their aircraft power units to air-cooled motors.

During the period immediately after the war, there was an inevitable general " let up," and certain of the new air-cooled engines planned during the war-time period were completed and brought into service in England, but gave indifferent results owing to inadequate development, and so we find that, in the early years of the last decade, the air-cooled engine, and especially the large air-cooled static radial, had received a serious setback, and water-cooled engines were almost universally used for military aircraft, and the first post war air lines. However, the large air-cooled static radial was not to be denied, and it returned to favour with increasing force early in 1924, and gained ground steadily for the next four years, until, at the end of that period, the majority of the power plants of the Air Forces of European countries used the air-cooled static radial type, and a similar change took place on civil work. On the latter type of aircraft, the air-cooled engine has held its position unchallenged, but competition came in again from the " V " in-line water-cooled engine for military aircraft, primarily inspired, I believe, by the remarkable results obtained with the American Curtiss engine in the Schneider Trophy.

About four years ago this competition was again felt, with the result that the air-cooled motor lost some prestige for military work, but the " swing of the pendulum " has turned once more, and the air-cooled engine is, I believe, in a sounder position to-day than it has ever been.

As already suggested, both forms of cooling will continue to be employed, but I feel that the come-back of the air-cooled engine has been on sound lines, and that it is likely to remain unchallenged for some considerable period for certain types of aircraft.

In America, I believe I am right in saying that the position has been somewhat different. When the large static air-cooled radial first came into its own in Europe in 1923-24 I remember reading some adverse criticisms of it in the current American Technical Press, but when the advantages of this type of engine were fully realised, it made the most wonderful strides in the United States. Since its development, and almost universal adoption, I believe I am right in saying that it has never had the same competition to face, in America, from the liquid-cooled engine, that has occurred in Europe, hence the fortunes of the air-cooled engine have been more stabilised in America than in Europe. The fact that the ring cowling of radial engines was more readily accepted, and applied, in America, had also had its influence on stabilising the large air-cooled radial engine in that country.

At the present time the air-cooled radial engine dominates the situation in America for both civil and miltary aircraft, up to and including the largest type of aircraft engine produced, and, from a recent visit to the States, I have gained the opinion that it is likely to remain so—at any rate for the next few years.

It may be fairly stated that the direct air-cooled engine holds an important position in aircraft in all countries of the world, and the object of this paper is to endeavour to suggest the lines on which this position can be maintained for the future.

Every form of mechanical design necessitates a compromise, and it is believed that the most fruitful line of action will be to concentrate and develop those special attributes of the direct air-cooled engine which make it practical and attractive for aircraft power plant, rather than to attempt to interpret it in a

form in which its shortcomings are emphasised, and in which it is doubtful if it can ever hope to compete. The advantages of direct air-cooled engines for aircraft power plants have so often been epitomised that I do not propose to enumerate these again at length, but, when considering the most profitable line upon which to work for the future, it would appear to me to be well to keep the following in mind:—

(1) Simplicity, low cost, and ease of manufacture.
(2) The ability to speed up manufacture rapidly in time of emergency.
(3) Simplicity of raw materials, and the ability to use forgings.
(4) Light weight, and the smallest possible compass.
(5) Rapid mounting and dismantling in the aircraft.
(6) Ease of servicing and maintenance.
(7) Rapid and low cost of repairs and renewals.

Section III.

Trend of Air-Cooled Aero Engine Development

How often have we heard the question: What is the greatest power that can be taken from an air-cooled cylinder, what is the maximum h.p. that can be obtained from an air-cooled engine, and when will a limit be reached? I believe that reliable answers to such questions are impossible, as development and technique are constantly changing, and I suggest that considerable advances will be made during the period under review, both in the power attainable from a given size of air-cooled cylinder, and in the total power that can be obtained from an air-cooled aero engine power plant.

When considering the future development of the air-cooled aero engine, it would seem to me that it is inadvisable to dogmatise on powers and weights without consideration of the purpose for which the engine is intended and the aircraft into which it is to be installed. For reasons quite apart from the interests of the engine, the weight and bulk that can be allowed for the power plant, in varying types of aircraft, are now fairly well defined, and it would appear that the most successful engine should be that one which fits into the requisite compass, combined with the attributes enumerated in Section (2). To this set of requirements should be added that the engine should obviously deliver as much h.p. as possible commensurate with a given standard of reliability, and adequate cooling conditions. These remarks may appear to be so obvious that they do not require mention, but it is considered that they are of vital importance when laying down the design of an air-cooled aero engine. It is considered that it would further assist design if a maximum bulk and weight for the complete power plant, accessories, and fuel and oil for a given range could be fixed for different types of aircraft, and closely followed.

The design and development of an aero engine power plant is nowadays such a comparatively long process that the aero engine designer has to lay his plans some years ahead, and, having fixed upon a certain type, it is usually impossible to make any radical change to the layout without entirely destroying the design. The difficulties of the aircraft designer are fully appreciated, but the engine maker sometimes looks with longing eyes upon the facility with which aircraft weights are apt to increase when necessity arises.

I understand that a study of the Prandtl theory on aeronautics reveals the fact that we must not expect any startling aerodynamic innovations, and that, in order to increase the efficiency and performance of aircraft, we shall have to rely upon detail improvements, such as better fuselage shapes, reduction of interference drag, retractable undercarriages, etc. In like manner, I do not anticipate any very radical changes in the type of the four-cycle internal combustion engine as used to-day, with possibly the exception of the power units for large flying boats and large civil aircraft. Rather do I expect to see detail

changes and developments, reduction in the volume of the engine, and improvement in fuel consumption.

To increase the performance of aircraft, I believe I am correct in stating that one of the easiest ways is to substitute a larger engine, provided the weight, shape, etc., are suitable. Broadly speaking, this has been the main line of attack to date, and sizes of engines have been, and still are, creeping up. I am quite convinced that a halt must be called to this procedure, as it does not make for efficiency and is apt to lead to a vicious circle, entailing larger and heavier machines, increased drag, larger fuel tanks, etc. By this I do not necessarily mean that the aircraft designer can continue to raise his performance curves by the use of less power, but rather that the engine maker must provide him with the same, or more, power from a considerably more efficient engine. Comparatively recently I have seen it stated that 30 to 40 cruising horse-power per passenger will be required for some time to come for a civil aircraft for general all-round efficiency. With this figure I am not prepared to argue, but I do insist that we must aim to provide this power from engines of smaller volume than at present.

At the present time, about 13 to 14 cruising horse-power per litre (61 cu. ins.) is accepted as the limit to take from an aircraft engine of current power/weight ratio, if long life between overhauls may be expected. This seems to me, with all the development at the back of an aero engine, a low figure, and should be capable of being considerably improved upon.

I feel that the aircraft engine of the future must follow the trend of the motor car engine in volume reduction, and we must aim at giving considerably more power from a given capacity, both for take-off and continuous cruising power. In 1920, 15 rated horse-power per litre (61 cu. ins.) was considered a reasonable output from an aviation petrol engine; to-day the figure is about 22-26 rated horse-power per litre, and I hope to see 40-50 rated horse-power per litre attained within the period under review. I exclude from these views the compression-ignition engine, which, for reasons explained elsewhere, I categorise as a special case.

I do not visualise any startling reduction in weight, as changes will have to be made to accommodate additional stiffness and bearing loading capacity, but, with the development of such a type of engine, many advantages will accrue, such as reduction in scale of the engine, increased overall efficiency, and reduced fuel consumption. Such changes, although not revolutionary, entail many problems, and, at this stage, it may be useful to discuss, in more detail, the main headings under which these desiderata may be obtained, together with other developments of current interest.

(a) Increase in Compression Ratio

Raising the compression ratio is one of the most useful means of obtaining a higher engine performance. Briefly, its effect is to increase the brake mean effective pressure, thermal efficiency, and maximum explosion pressure, and to decrease the residual exhaust gas temperature and fuel consumption.

The improvement obtained is limited by detonation, which problem has already been attacked with a fair degree of success by the fuel technologists, who have introduced fuels of high anti-knock value, and have carried out considerable investigations on the use of anti-detonants.

Apart from the question of detonation, progress in this direction will be limited by the maximum explosion pressure at which engines may be allowed to operate safely. The problem of the maximum permissible cylinder pressures is one which is causing some discussion at the present time, and will, I think, be governed by consideration of the fuel available for the combination of optimum compression ratio and boost pressure.

(*b*) *Effects of Increased Compression Ratio on Design*

The increased gas pressure can be offset, to some extent, by higher inertia loading, obtained by increasing engine speed. Stresses in articulated pins and gudgeon pins will be increased, and these parts will need attention. In certain quarters it is felt that pistons will have to be modified to withstand the higher loads, but I think that if pistons are of sufficient section to provide adequate cooling, they will be strong enough to stand the increased loads due to increase in compression ratio. The key to the problem would seem to be, therefore, is it possible to provide adequate cooling to the piston without increasing the weight to dangerous limits? I would suggest that this is possible on the smaller bore cylinders, but, when it comes to the larger size pistons, the problem will undoubtedly be serious in order to prevent abnormal piston temperatures with consequent ring sticking. To overcome this difficulty, I think some considerable development work will be necessary, and the engine maker will either have to look to the material suppliers for some new alloy or, alternatively, introduce some better means of dissipating the heat from the piston, without recourse to methods giving excessive weight, such as sodium cooling.

The provision of satisfactory exhaust valves and seats is rendered easier by the reduction in exhaust gas temperatures, due to the higher expansion ratio.

(*c*) *Fuels*

From the aspect of detonation, as affected by compression ratio and boosting, fuel becomes one of the most important factors influencing advance in these directions, and has been an obstacle to progress in England during the past few years.

It must be realised that fuel problems in England and Europe are of a somewhat different nature from those existing in America. We have no home product in England, with the exception of small experimental quantities, and all our fuels are imported.

Our civil air lines, operating over many different countries, have to use a wide range of fuels, as standardisation is nothing like so easy a problem as in one large continent, such as America.

Our Air Force has also to operate in many different countries, and our imperial position is an important factor which seriously affects the fuel question.

Little imagination is needed to realise that an engine running continuously at any considerable throttle opening, on a fuel which detonates, will encounter a whole series of troubles, which, if allowed to persist, may rapidly entail the total wreckage of the engine.

Until quite recently no country, with the exception of America, has taken this problem seriously and standardised a fuel of high octane number. America has standardised an 87 octane number fuel for military aircraft, for some time past, and, in April this year, issued a 92 octane specification.

A number of different types of liquid hydrocarbon fuels, suitable for electric ignition engines, are available, the principal being as follows:—

(*a*) The straight run (or normally distilled) fuel.

(*b*) Cracked fuels, which are produced by a high temperature process, which can be made to rearrange the hydrocarbon groups, giving higher anti-knock values than those obtainable from a straight run spirit from the same crude.

(*c*) Blended fuels, consisting of mixtures of straight run spirits, or spirits to which benzol or other aromatics have been added, to give a higher knock rating.

(*d*) Hydrogenated fuels, in which the original hydrocarbons have been converted by a hydrogen treatment into compounds of higher knock rating.

(*e*) Alcohol fuels, which are of a very high knock rating, but the use of which is usually limited to racing, or other special events, where cost and high consumption, due to low calorific value of the fuel, are not factors of prime importance.

All these fuels are available in varying degrees in different parts of the world, although the hydrogenation process is as yet only in an experimental stage.

The characteristics of a straight run fuel depend greatly on its origin, and thus the quality and type of fuel, found in any part of the world, will obviously depend on a number of factors, such as the type of crude base most readily available, transport facilities, magnitude of sales, etc.

The British Air Ministry have, in the past, standardised an aircraft fuel with octane number of 73, while 80 octane number has been available for military aircraft engines in certain European countries during the last year, and 70-73 octane number the average employed on civil air lines.

Fuel of 77 octane number has been standardised by the Air Ministry this autumn, and it is proposed to introduce a fuel of 87 octane number in 1934.

The necessary increase in octane value can be obtained, with a blended spirit, by the addition of a considerable percentage of aromatics, but the chief disadvantage of this combination is that its knock rating is seriously impaired by elevated temperatures. For all high efficiency engines, and, in particular, air-cooled engines, this is a serious failing, and, undoubtedly, the most generally satisfactory combination is a straight run fuel of high naphthene content, and good lead susceptibility, with the addition of a small percentage of tetra-ethyl lead.

Such a fuel has other important advantages over a petrol-benzol mixture, as trouble can be expected with benzol mixture at high altitude, or in cold climates, owing to the high freezing point of benzol. Moreover, supplies of benzol would be unobtainable in the event of hostilities, as it would be required for the manufacture of explosives.

In this connection, I should like to stress the necessity of putting forward, for international agreement, the method of determination of octane numbers, as considerable confusion exists at the moment, and different countries have adopted varying types of test engines and conditions in the standardisation of fuels.

With suitable engine modifications, the difference in B.M.E.P. obtained between an 87 and 73 octane fuel is in the order of 20lbs., and the increase of power obtainable from such an engine as the Bristol " Pegasus," using fuels of varying octane numbers, is shown in the tabulation in Fig. 1 together with the specific weight reduction and the comparative fuel consumption based on a cruising power of 400 brake horse-power.

BRISTOL PEGASUS ENGINE.

EFFECT OF FUEL OCTANE VALUES ON ENGINE PERFORMANCE.

Min. Octane Value.				Relative Power Output.				Fuel Consumption.	
D.T.D. Specification.	Determined according to A.M. Spec.	Determined according to U.S.A. Army Spec Y. 3557 G.	Lead Content for Representative Fuel. Mls. of T.E.L. per imp. gall.	At Normal R.P.M.		At Maximum R.P.M.		Lbs./B.H.P. Hr. at Normal Power.	Galls./Hr. Cruising at 400 B.H.P.
				B.H.P.	Lbs./B.H.P.	B.H.P.	Lbs./B.H.P.		
134	73	69	nil	525	1.95	570	1.8	0.55	27.5
224	77	73	nil	560	1.84	610	1.68	0.53	26.5
230	87	85	4	665	1.54	715	1.43	0.49	24.5
—	—	92	6	735	1.42	790	1.32	0.47	23.5

N.B.—Weights of these engines suitably adjusted for increased stresses.

FIG. 1.

I hope that in the above very elementary review of the possible hydrocarbon fuels available for electric ignition internal combustion aircraft engines, I have emphasised sufficiently the great value of the lead taken by America in introducing a fuel of high octane value.

Such a fuel is of paramount importance, both for civil and military engines, and the necessity of solving the problem of its supply, on a commercial basis, cannot be too strongly emphasised. I do not consider that I am stating the matter too highly when I say that there is no question of greater importance to engine development at the moment.

I believe the best solution for a high octane value fuel is by means of the addition of a reasonable quantity of tetra-ethyl lead, say 4 c.c.s per gallon. It would appear that it is not wise at the present time to exceed 4 c.c.s per gallon, as available fuels show a poor lead consciousness with higher concentrations, and the actual engine problems are considerably increased.

The introduction, by the Air Ministry, of an 87 octane number fuel, referred to above, will be greatly appreciated by the air-cooled aero engine designer, and will give scope for considerable development on military engines, and it is hoped that fuels of not less than 80 octane number will, at the same time, be available for civil air lines.

The use of tetra-ethyl lead introduces a number of problems not encountered with normal fuels, including corrosion of valves, valve seats, cylinders, etc., and recent developments have shown the wisdom of the Air Ministry in limiting the lead content to 4 c.c.s per gallon in the new specification.

A considerable amount of experimental work has been going on to overcome the deleterious effects of lead, and I will refer to this matter in more detail later on in the paper. The question of the internal corrosion of engines, using high lead content, after standing for long periods, or in stores, and the harmful effects on exhaust systems, are also problems which require attention.

While the higher octane number specifications referred to are a " step in the right direction," and will show considerable improvement in engine output, I would emphasise the necessity of immediately making preparations so that the octane number may be further raised at a future date, in order that the development of the air-cooled aero engine which is possible, within the period under review, may be realised.

Considerably more attention must be paid to the importance of fuel consumption on air-cooled engines, and, apart from the standard type approval tests, Bristol engines have recently been subjected to a 50 hours' cruising consumption test, in order to establish the minimum consumptions which are allowable.

Fig. 2 shows the figures attained on a recent consumption test with the Bristol " Pegasus " M. engine.

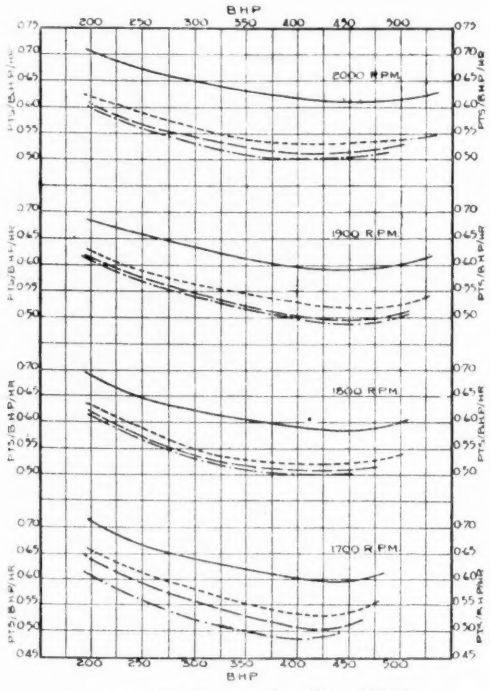
The figures appearing on this slide are in no way the ultimate to be aimed at, but are quoted as showing that the consumptions of air-cooled engines are capable of treatment, and it is believed that by development along suitable lines, a considerable further improvement can be made, from the point of view of fuel economy with the compression ratio as high, and the boost as low, as is feasible.

(*d*) *Supercharging*

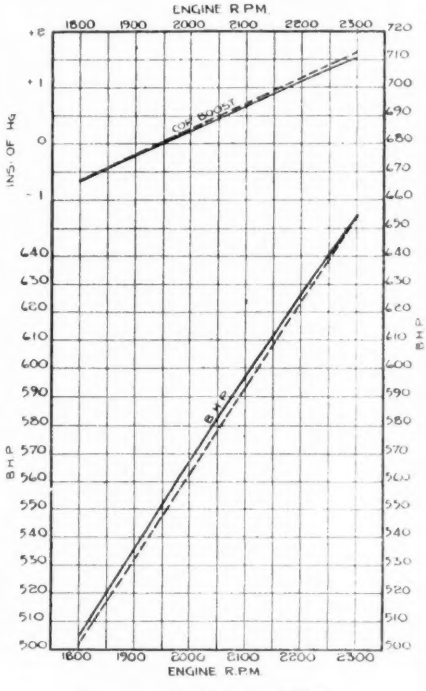
Supercharging briefly consists of increasing the density of the charge by means of an external compressor, and is one of the most outstanding developments of the modern aircraft engine.

The principle of supercharging aircraft engines has been applied with two objects in view. Firstly, the maintenance of ground level induction pipe pressures and powers, at high altitude, and the other—the increase of ground level power over and above that which is possible by natural aspiration; this latter form of supercharging being commonly known as ground boosting. Until comparatively recently, there were two distinct schools of thought on this matter—

the European designers adhering to the former method, while the American trend, with their better fuel, was towards the latter. Both adherents have now somewhat modified their views, and, for the high-powered supercharged engine, it has been found necessary to give the engine a certain amount of positive pressure for take-off, while the exponents of ground boosting have found it incumbent upon them to increase the rated altitude of their engines.



Pegasus 11-*M. Engine No.* 15101.
Constant Speed Power-Consumption Curves.
———— Normal Rich Mixture.
— — — — — Weakest Mixture for Maximum Power.
—— —— —— Mixture for 1½% Drop in F.P.M.
— · — · — · — Mixture for 3% Drop in R.P.M.



Pegasus 11-*M.3 P.* 15101.
50 hrs. Weak Mixture Test (July, 1933).
Conditions of Test: 400 b.h.p. at 1900 r.p.m. at 0.5 pts./b.h.p./hr. (Average).
Full Throttle Power Curve at 5000 ft.
———— Curves at Commencement of Test.
— — — Curves at Conclusion of Test.

Standard Test Conditions—A.I.D. Approved.

FIG. 2.

On the earlier supercharged engines it was considered permissible, by certain engine constructors, to compensate for rather inadequate breathing organs by ground boosting, and a number of engines have been put into production, in which the valves and porting system have been on the small side, thus easing design and production, and it has been hoped by this means to obtain good efficiency. The experimental work of the Bristol Company has conclusively proved that this is bad practice. To obtain satisfactory and efficient supercharging, the engine must start off with the freest and most efficient breathing functions possible, as restricting the valve and port areas, and then super-

charging only leads to a series of difficulties, and the aim should be to obtain the maximum power at rated altitude with the minimum positive boost.

It is interesting to note that the latest examples of American engines are now employing the largest possible valves and port areas for supercharged engines.

With a supercharged engine, for a given increment in horse-power, the advance in explosion pressure is not so great as that obtained by increasing the compression ratio, but the cylinder and exhaust gas temperatures are considerably higher, so that cooling difficulties are greatly intensified, and fuel consumption

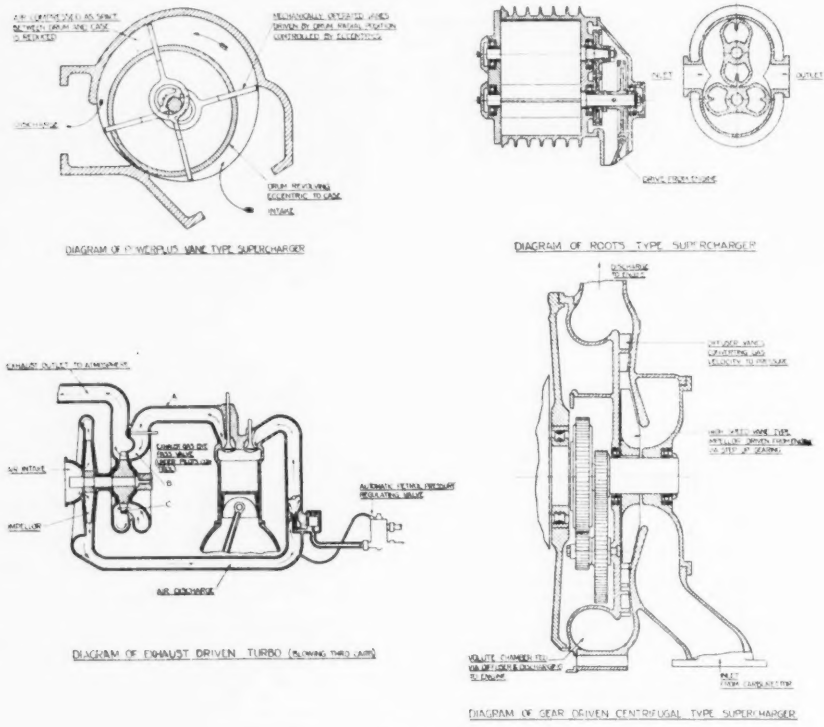


DIAGRAM OF ROOTS TYPE SUPERCHARGER
DIAGRAM OF EXHAUST DRIVEN TURBO (FLOWING THIRD LAW)
DIAGRAM OF GEAR DRIVEN CENTRIFUGAL TYPE SUPERCHARGER

FIG. 3.

is adversely affected, while the extent to which intake pressures may be increased is again limited by detonation, although the use of an intercooler raises the permissible limit.

A considerable amount of research work has been carried out on the design of superchargers for aircraft engines, and some data has been drawn from parallel work on the supercharging of motor car engines. To attempt to review in detail the work which has been achieved is beyond the scope of this paper; it is sufficient to say, however, that, up to the present time, superchargers for aircraft engines have been mainly confined to three types—the mechanically driven centrifugal fan, the exhaust driven turbo compressor, and the direct displacement blower, chiefly of the Roots type. Fig. 3 shows these types in diagrammatic form. By far the greatest number of aircraft engines to-day employ

the mechanically driven centrifugal fan type, for the reason that it has been found to be the easiest, the lightest, and the most compact form to adopt, taking into consideration the comparatively limited speed range of an aircraft engine. There is little to choose between the efficiencies of these types, and, at the moment, it is difficult to envisage any marked improvements in this direction. The centrifugal fan type has an overall adiabatic efficiency of about 60 to 65 per cent., and the direct displacement type, such as the Roots, a peak efficiency of about 75 per cent.

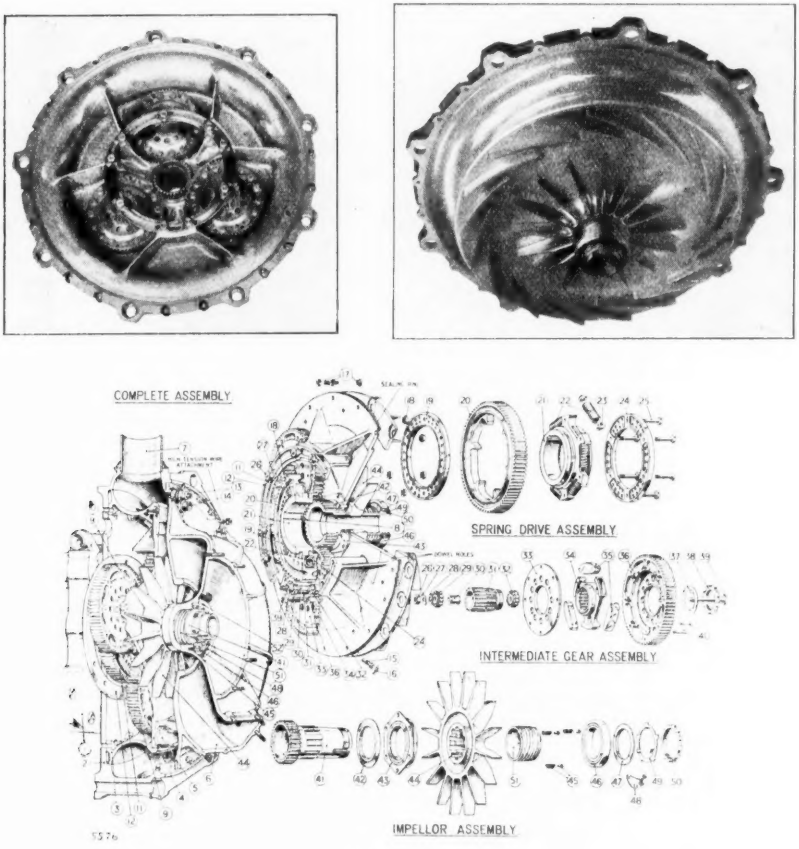


FIG. 4.

Fig. 4 shows the centrifugal type of supercharger as applied to the present series of Bristol engines.

Fig. 5 shows the Alfa-Romeo " D " type radial engine, with the Roots type of displacement blower built into the rear of the crankcase.

It is interesting to note that the engines fitted with the two blowers just illustrated—the Bristol centrifugal fan type and the Alfa-Romeo displacement type—were taken to the Stelvio Pass in the Alps, in the summer of 1932, mounted on special portable test benches, and calibrated under actual altitude conditions

of 9,000 feet, a full analysis being made into the relative efficiencies of the two types of blower. This proved to be an interesting test, and is, I believe, the first time that such a comparison has ever been made in Europe.

Fig. 6 shows the Bristol " Mercury " engine actually on test on the Stelvio Pass, in July, 1932.

An investigation of the analysis of the comparative efficiency of the two blowers, powers, fuel consumption, etc., showed that while both engines were slightly down on their estimated powers, the Bristol centrifugal fan type very nearly approached the altitude rating as determined by the conditions imposed by Air Ministry Publication 840—Schedule of Standard Type and Production Tests for Aircraft Engines.

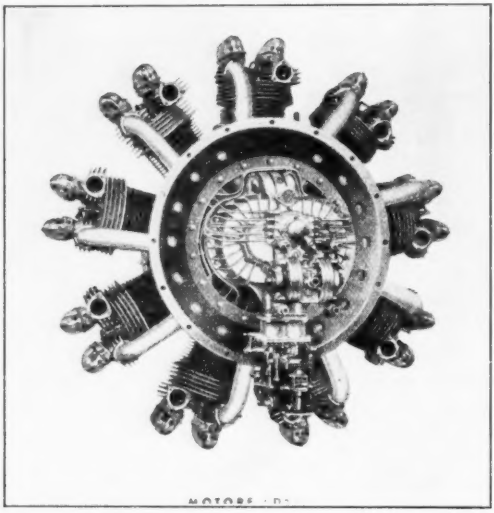


FIG. 5.

To determine relative efficiencies, so much depends upon a quantity of detail data, and definite conclusions without the fullest facts are sometimes apt to be misleading. I do, however, suggest that there is not very much to be expected in increased efficiency with either of these two types of blower.

The Bristol Company have recently completed an exhaustive research for the British Air Ministry on geared centrifugal type superchargers, covering some fifteen months' work, and including an investigation into different types, diameters and clearances of impellors and diffusers, impellor bearings, etc., from which we have been able to obtain a fair idea of the possibilities of this type of blower, and the detail improvements that may be expected.

Where it is necessary to maintain reasonable power for take-off and climb, it is not thought possible to use a single stage blower of centrifugal type with a compression ratio of more than 1.85 to 1 (giving a rated altitude of 15,000 feet), owing to the power losses in the blower when running throttled on the ground, and the limitations entailed by cylinder compression ratio and fuel available.

As regards the exhaust turbo compressor, the Bristol Company produced the first British air-cooled radial engine to fly embodying this principle, in 1923. Since that date, two or three other applications of this system have been made by engine makers in England. In my opinion, owing to certain difficulties in the

original layout and the materials used, the exhaust turbo compressor has been unduly condemned, and I think we shall hear more of this type at a future date.

Owing to the fact that it is possible to bye-pass excess mixture at low altitudes, with the Roots type of blower, and, therefore, minimise the power taken to drive the blower, it has been suggested that this would make an attractive unit for the radial air-cooled engine, and that it should be possible to maintain rated boost to 20,000 feet and still obtain reasonable take-off power.

While it is possible that the Roots type of blower may be introduced on in-line engines, its shape and dimensions are such that it can only be incorporated on a large static radial with difficulty, and at the expense of a considerable increase in bulk and weight. There are other difficulties with the Roots type of blower, which militate against its adoption in larger sizes, such as increased noise, and mechanical difficulties due to the close clearances necessary to maintain efficiency. I do not feel, therefore, that the adoption of this type of blower is a promising solution for an air-cooled engine.

FIG. 6.

Up to the present time none of the other types of direct displacement blowers which have been produced, has shown any promise for aircraft engines owing to mechanical difficulties, bulk, and weight.

What developments may we expect to the supercharger, during the period under review?

(*a*) I suggest that we shall see some form of compressor standardised on every aircraft engine, following out directly the trend of thought of increased output from a given swept volume.

(*b*) When it becomes necessary to restore the ground level power of aircraft engines, at a greater altitude than has been accomplished at present, approximately 15,000 feet, still maintaining reasonable take-off power, I suggest the two-speed centrifugal blower offers the most practical solution, and I think there is no doubt that we shall see considerable development in this direction during the next few years. It is debatable if the weight and the complication of the two-speed blower are justified unless the rated altitude is raised in excess of 15,000 feet, in which case inter-coolers will be required. Such inter-coolers must not be excessively heavy or bulky, nor of high drag, and their design is a problem which will demand considerable ingenuity for incorporation in in-line or radial type engines.

(*c*) If the demand for restoration of power at still higher altitudes becomes insistent, I incline to the view that there may be a reversion to the exhaust turbo compressor, as this scheme, in somewhat modified form, offers many advantages.

An interesting engine appeared at the Paris Salon of last December, incorporating some of these modifications, and Fig. 7 shows two views of the 12-cylinder horizontally opposed Potez engine. This is the first concrete attempt

to interpret the late Mr. Rateau's final views of the exhaust turbo system, to avoid the disadvantages met with in the earlier types.

The cycle of operations is as follows:—

(i) After explosion, the first exhaust valve which is connected to the turbo charger, opens, and the initial blast of hot exhaust gas drives the turbo compressor.

(ii) At the end of the firing stroke, the second exhaust valve begins to open, in order to permit an uninterrupted exhaust; thus the engine is not required to function under any back pressure.

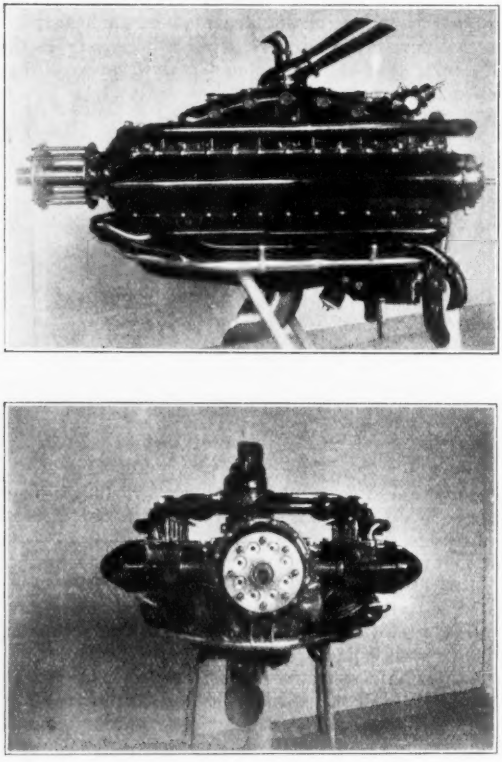


FIG. 7.
Moteur H. Potez Type 12AS a Turbo-Compresseur Rateau.

(iii) Both exhaust valves close at the end of the exhaust stroke and one inlet valve opens, admitting pure air from one half of the blower.

(iv) Towards the end of the induction stroke, the second inlet valve opens, to admit very rich mixture, which is supplied from the second half of the blower, in conjunction with a single choke zenith carburettor for each bank.

(*d*) A demand for greater increase in the restoration of power at altitude will increase the problem of engine cooling, which I am dealing with under a separate heading.

(e) *Engine Cooling*

As I have endeavoured to outline in this paper, both supercharging and increasing engine speed entail the dissipation of more heat in a given time, and, therefore, if the air-cooled engine is to maintain its position, cooling technique must be developed.

The cooling problems connected with direct air-cooled aero engines cover such a wide scope that it is impossible to deal with the main headings more than briefly in this paper, as follows:—

(1) The prevailing conditions under which direct air-cooled engines usually operate.
(2) The detail design of flight-induced air-cooled cylinders.
(3) The ring cowling of radial air-cooled engines.
(4) The fan cooling of air-cooled engines.

Referring to heading (1)—the prevailing conditions under which direct air-cooled engines usually operate—I suggest that it is necessary to endeavour to visualise the aircraft, as far as possible as a whole, if the best results are to be obtained, and that the laying of too much emphasis on engine cooling, or certain aspects of the aircraft, will not make for the most satisfactory combination. At the present time it is standard practice for British military aircraft to climb at a considerably steeper angle and lower air speed than is the case in certain other countries, and, while I do not propose to criticise this practice, it will be appreciated that it throws a considerably more arduous duty on the cooling of the engine, and there is no doubt that many direct air-cooled engines, which would function quite satisfactorily in certain foreign aircraft, would give serious trouble, in a short period of time, in our military service, and it must be obvious that an engine which will operate at a climbing speed of 140 m.p.h. with open exhaust is quite inadequately cooled at a climbing speed of 95 to 100 m.p.h. with a complete exhaust system.

In a similar way, for a number of undoubtedly perfectly good reasons, upon which I do not propose to dilate or criticise in this paper, the shape of the fuselage immediately behind the air-cooled engine is sometimes very disadvantageous from the point of view of the best cooling, and, in some extreme cases, I do not think it would be an exaggeration to say that the engine designer is tempted to wonder how his engine is ever going to cool, and why it is necessary to endeavour to reduce the compass of the engine. I realise that there are many real difficulties on both sides, to which must be added the laudable desire of the British aircraft designer for gearing, and the highest rate of supercharge possible, but, before leaving this matter, I would ask the aircraft constructor to appreciate that many valuable pounds of weight in cylinder construction must be sacrificed in order to endeavour to meet these conditions.

Turning to heading (2)—the detail design of flight induced air-cooled cylinders—the cooling surface of any engine must dissipate a quantity of heat equivalent to approximately 60 per cent. of the brake horse-power. In the case of the flight induced air-cooled engine, the ability to cool is dependent upon the fin area required to effect this rate of heat dissipation, the detail design of the cylinders, and the installation conditions.

Until recently, six square inches of cooling surface per cubic inch of cylinder volume was considered normal practice, but at the present time 11 to 12 square inches are employed on the most up-to-date geared and supercharged engines. During this period under review, the introduction of higher output and considerably higher rotational speed will entail, I suggest, an approach to 15 to 20 square inches per cubic inch of cylinder volume.

It is possible for a designer to add excessive fin area without increasing the effective cooling capacity, and in this connection, the recently published work of Mr. D. R. Pye, Deputy-Director of Scientific Research, Air Ministry, provides

an excellent summary of the essentials of air-cooling, and he has stated that the minimum allowable clear space between fins if interference of boundary layers, and the consequent drop in heat dissipation, is to be avoided, appears to be .15in., when the air has to flow between the fins for a distance of 6in. from the leading edge in the downstream direction.

With the increased compression ratio and high boost used with high octane fuels, resulting in greatly increased specific power output, it seems necessary to ensure that the whole combustion chamber is made as free as possible from any local points which may overheat and cause detonation. Sparking plugs must be of a suitably high heat resistance type, and be capable of withstanding the effects of ethyl fuel.

Another point on the combustion chamber, which is shown up with the higher specific outputs, has been the gas starter non-return valve. This valve, when not maintained in first-class condition, may leak slightly, thus rapidly overheating and initiating detonation. It is suggested that this valve should be entirely eliminated, thus removing possible danger and also helping to make a stronger cylinder head and less interference with the finning.

With the higher duty engines, it is of the utmost importance that cylinder temperatures should be observed whilst running, as this provides a most ready means for telling whether the engine is working satisfactorily, and that detonation is not being caused through any reason such as inferior fuel. The Bristol Company have long advocated the use of a pyrometer system on air-cooled engines, as the air-cooled engine is long suffering and has no immediate way of making its complaint known such as exists in the boiling of the cooling water of a water-cooled engine.

With air-cooled engines of high output it is considered more essential than ever to standardise some form of cylinder temperature measuring equipment. This practice is established in America, and by the selection of a suitable form of thermo couple, which can be permanently attached to two or three representative cylinders and one position on the crankcase, together with an indicating instrument, a perfectly reliable system can be obtained, and I suggest that this equipment should be standardised on future high output air-cooled engine installations.

It has been suggested that a compromise of air-cooled barrels and permanently sealed Prestone-cooled heads might prove a possible solution, and, although I must confess to having gone so far as setting down such schemes on paper, my present view is to adhere definitely to the direct air-cooled engine.

With the present system of flight induced cooling of the air-cooled engine, cylinder arrangement, of necessity, affects the capacity for cooling available, and this aspect of air-cooled engine development will be dealt with later on in the paper.

The Bristol Company have been fully alive to the necessity of development of cowled installations with flight induced cooling to meet the arduous conditions of British military aircraft already outlined, and a considerable amount of interesting data was obtained in connection with cooling problems during the experimental flight tests made by Mr. Uwins when preparing for the World's Altitude Record in the autumn of 1932; and, at altitudes of 40,000 feet and over, it was found that cooling and cowling technique were matters of the utmost importance.

With this end in view the Bristol Engine Research Department has concentrated on this problem during the past three years, carrying out a series of experiments comprising some thousands of hours' full throttle running, and including a series of breakdown tests carried out under abnormally low wind speed and high temperature conditions.

As it was impossible to obtain the necessary high temperatures under the standard full throttle test conditions, a special breakdown test bed was initiated

by the Bristol Company, in which the cooling wind speed was reduced to 60 miles an hour, and a baffle board was arranged at the rear of the cylinder in order to obstruct the get-away of the cooling air, the unit being run continuously at full throttle (2,100 r.p.m.), corresponding to a main engine power output of 600 brake horse-power. Standard fuel to Air Ministry D.T.D. 134 specification, 73 octane (68 octane number by C.F.R. motor method) was used, and the fuel consumption limited to 0.58 pts./brake horse-power/hr. throughout.

Under these conditions the " Jupiter " type cylinder failed after 60 hours, and, as a duration of at least 100 hours was the standard set to ensure satisfactory life under service conditions, it was evident that the cylinder design would need careful consideration in order to make the cooling capacity satisfactory for use with ring cowling.

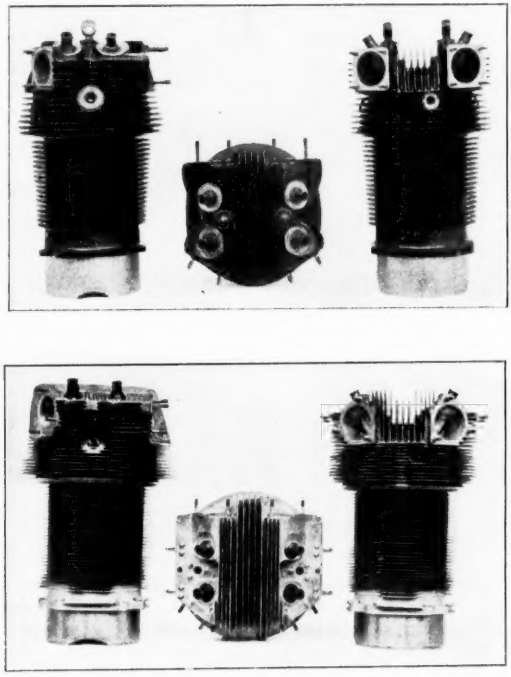


FIG. 8.

In the course of the series of experiments carried out during the evolution of a cylinder capable of coping with these conditions, twelve different types were designed and tested before the present " Pegasus " cylinder was evolved. It was found possible, with the lower wind speeds, to reduce the pitch of the cooling fins by 50 per cent. without loss of cooling efficiency, and, by this means, together with an extension of the finned surface, the total cooling area was increased by 66 per cent. With this cylinder the temperatures obtained, under the original breakdown test conditions, were so low that the test would have failed in its object, and it was considered desirable to increase its severity. The wind speed was, therefore, further reduced to 40 miles per hour, the lowest operating speed obtainable with the plant.

Despite the lowering of the wind speed by 30 per cent. below the " Jupiter " type cylinder test conditions, the " Pegasus " cylinder tests showed a drop of the order of 10 per cent. in the cylinder and exhaust valve temperature. Under these abnormal conditions the 100 hours test was completed with entire satisfaction, the performance being well maintained, and, at the conclusion, the cylinder, valves, and seats were in first-class condition; the unit being retained for further high duty test running. Since the clearance of this cylinder, it has been run continuously for long periods under heavy duty on the single-cylinder test bench with complete success and without any sign of breakdown or failure. To date, approximately 700 hours have been completed, a final check test made comprising over 300 hours' running at 2,200 revolutions per minute, with a normal climbing

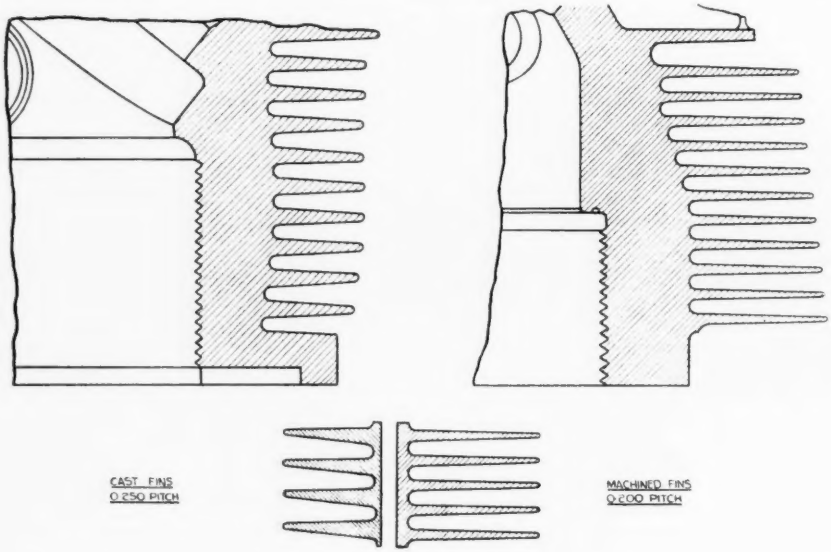


FIG. 9.

Relative air passages with cast and machined fins.

speed of 90 miles per hour. Under these conditions 150 hours were run at a brake mean effective pressure corresponding to the engine rating, followed by another 150 hours at 10 per cent. increase in brake mean effective pressure, and a final 20 hours' run at 30 per cent. in excess of the rated brake mean effective pressure.

Fig. 8 shows side and plan views of the latest " Pegasus " cylinder as compared with the " Jupiter " cylinder, the former type having shown itself capable of running satisfactorily under low wind speed and full throttle test conditions for such long periods that it is considered satisfactory for the life of the engine under all reasonable cowling conditions.

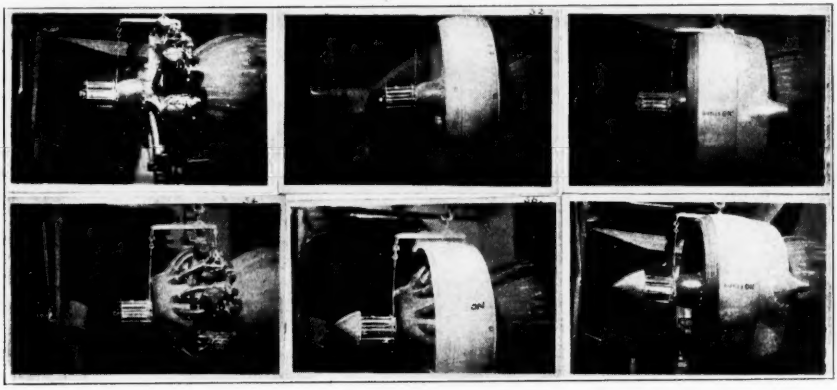
Such results have been made possible only by the forged head design of cylinder, on which, with modern machining methods, the increased cooling area has been obtained by close-pitched deep but efficient finning, which it would be impossible to produce by any form of sand or die casting. In this connection the Bristol Company consider that the maximum benefit can only be derived from close-pitch finning when these fins are machined from a solid forging, as the air spaces between the fins of a cast close-pitch fin surface are necessarily curtailed

by the minimum thickness of fin which it is possible to cast for any given depth. Fig. 9 illustrates the advantages of machined fins.

Whereas it is realised that the all-machined cylinder does not give one the same scope of change in design, it is quite a wrong impression to consider it a more costly job. Actually the Bristol Company are producing their forged heads at a lower cost than the cast ones, and there is no doubt that the forged head offers accurate precision methods for producing consistent air-cooled heads in large quantities, which cannot be approached when the head is in cast form.

It is of interest that in some respects the finning of the latest Bristol cylinder resembles that of the original " Jupiter " of thirteen years ago, the barrel of which had five fins to the inch. Since then, as the speed of aircraft increased, the pitch was increased to allow penetration of the air to the root of the fins, while now that ring cowlings have resulted in a lowering of the wind speed round the cylinders, it has been necessary to go back to the closer pitch of fin.

Naked engine. *Short chord ring cowl.* *Combined long chord ring cowl, nose type oil cooler and rear exhaust ring.*



Standard front exhaust ring. *Short chord ring cowl, standard front exhaust ring and airscrew hub nose cap.* *Nose type oil cooler, rear exhaust ring and airscrew, hub nose cap.*

FIG. 10.

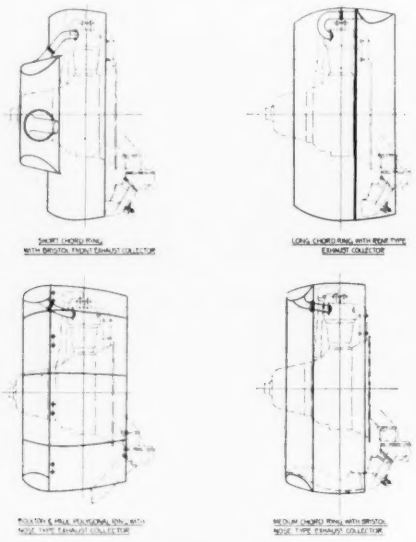
Full-Scale Tests in Vickers 8ft. Diameter Wind Tunnel. Pegasus Engine Mounted in Front of 4ft. Diameter Nacelle.

Turning now to heading (3)—the ring cowling of radial air-cooled engines —I do not propose to attempt to touch on the aerodynamic problems, but only to endeavour to explain a few of the difficulties from the engine cooling aspect. A study of ring cowling as applied to British aircraft, compared with types advocated by the American N.A.C.A. Reports and in common vogue in that country, would lead the casual observer to assume that there are considerable discrepancies, but I suggest—and will endeavour to explain—that there are perfectly logical answers. At the outset it may be desirable to state that the increase in cooling problems caused by ring cowling has been checked under full-scale conditions by the Bristol Company, through the courtesy of the Vickers Company who loaned their wind tunnel for investigating a " Pegasus " engine in front of a stream-lined body with various types of ring cowling. Fig. 10 shows the different aspects of these tests, and, although it was not possible to obtain accurate drag figures with the different types of ring cowling tested out, the flight results were entirely confirmed, the air speed over the cylinders being

reduced to 75 per cent. when ring cowling was fitted to the engine, as compared with the figure obtained with a bare engine in front of a stream-lined body.

For reasons already suggested in this section, it is standard practice on British military aircraft to fit short or moderate chord ring cowling with a considerable gap between the cowling and the front of the fuselage. With this type of cowling, inter-cylinder baffles to assist engine cooling have proved disadvantageous from a drag point of view, and, with the fuel available up to the present time, it has been deemed advisable to keep cylinder temperatures down to a conservative figure, and I should expect it to be extremely difficult to maintain these temperatures, in conjunction with a complete exhaust system, with anything but single row radials.

The Bristol Company standardise four types of ring cowling for military aircraft, as shown in Fig. 11, viz.: Small diameter forward exhaust ring and



APPLICATIONS OF BOULTON & PAUL TOWNEND RINGS TO BRISTOL ENGINES

FIG. 11.

plate ring cowl; rear exhaust ring combined with plate cowl; Boulton and Paul polygonal combined exhaust ring and plate cowl, and Bristol large diameter front exhaust ring combined with plate cowl.

On American installations, long chord N.A.C.A. cowlings are, I understand, supplanting the shorter type on single row radials, and also on some of the new double row engines, with success, and when using gearing and supercharging, but with higher climbing speed and higher cylinder temperatures than are permitted on British military aircraft.

With the introduction of fuels of higher octane number, I suggest that we may be able to approach more nearly the cylinder temperatures which are permitted with these American cowlings. These N.A.C.A. cowlings have a smaller inlet than is standard on the Townend rings used on British aircraft, the bodies immediately behind the cowlings are very carefully shaped to the correct contour, and great attention is paid to appropriate proportioning of the annular space of the outlet. The cylinders are fully baffled, and a comparatively smaller volume

of air scrubs the cylinders more effectively, with a consequent lowering of the drag over the body of the aircraft. Although it may be impossible to employ this type of cowling on British single-engined aircraft, I see no reason why this type of installation should not be applied with satisfactory results on multi-engined installations. Fig. 12 shows the latest type of American N.A.C.A. cowling as applied to the "Cyclone" geared and supercharged engine. The question of accessibility, weight, and robustness of cowling for radial air-cooled engines is a point upon which some attention is required, and I suggest that an important development along this line is for the engine maker to standardise the complete equipment.

With regard to heading (4)—the fan cooling of air-cooled engines—it is quite conceivable that the ultimate solution of the cooling problem will lie in the

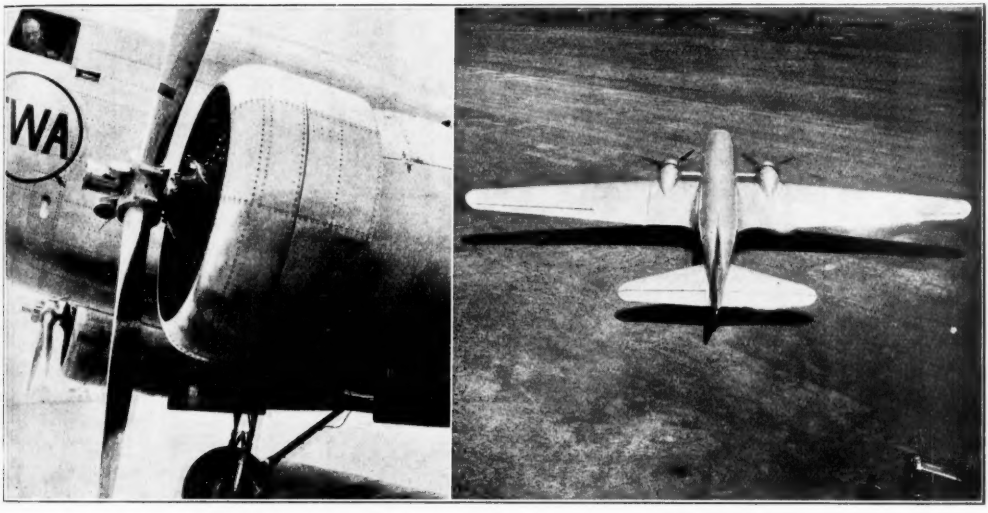


FIG. 12.

The Douglas Air Liner with latest N.A.C.A. cowling for "Cyclone" geared and supercharged engines.

permanent enclosure of the air-cooled engine in a suitable duct, and cooling it by an engine-driven fan. Up to the present time such a scheme has not made headway, chiefly, I believe, because it entails a specialised form of aeroplane fuselage for its suitable installation, and the demand for aircraft engines has not been sufficiently great to justify its introduction. As types of aircraft become more crystallised, this form of engine is likely to come into being. This view was supported by Mr. R. McKinnon Wood, in a recent paper on engine cooling research which he read before the Royal Aeronautical Society, and I understand that research work is continuing at the Royal Aircraft Estabilshment on these lines.

During the period under review I expect to see steady development in the technique of cylinder cooling and finning, a further increase in the fin area per cubic inch of swept volume, and a number of installations with fan-cooled engines and controllable cowling.

(f) *Increase in Rotational Speed*

(i) *Methods of Breathing the High Speed Aero Engine of the Future*

One of the most logical methods of obtaining more power from a given swept volume is by increasing the crankshaft speed, and I suggest that this step must be faced during the period under review, but it brings in its train a whole series of knotty problems, such as the breathing capacity of the cylinders, improved technique of valve mechanism, strength and rigidity of the crankshaft and connecting rods (the loads on many of the moving parts being increased as the square of the speed), and the necessity of providing reduction gearing to maintain an efficient propeller. These problems are all quite separate from cylinder cooling, which has already been dealt with, and in the time available an attempt will be made to touch upon, very shortly, some of the most important factors.

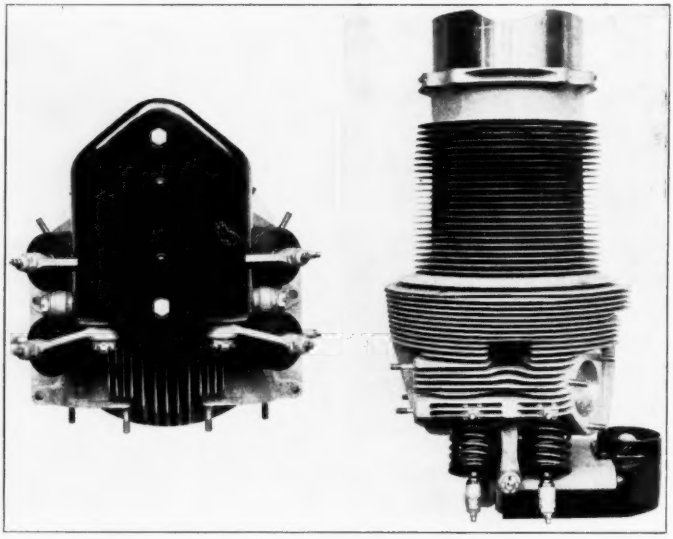


FIG. 13.

Increase in speed is limited primarily to the breathing capacity of the engine, and, as stated previously, it is considered bad practice to utilise the blower to force mixture through the valves—except for short periods of ground boosting for take-off purposes. A recent investigation has been made into the pros and cons of two and four valves for large capacity cylinders, and, while two valves offer certain advantages for simplified operation, lightness and cooling, there can be no doubt that four valves per cylinder give a much greater ratio of port area to piston area. Inlet gas speeds of 300 feet per second are by no means unknown with two-valve designs, whereas there is no doubt that the optimum speed should be of the order of 180 feet per second.

With a cylinder of 3 litres (183 cu. ins.) capacity, it is considered that it will be absolutely necessary to embody four valves, when running at speeds in excess of 2,200 revolutions per minute, if the necessary efficiency is to be obtained. For a given size of cylinder, the area past the valve can be increased by 20 per cent. by using four valves instead of two, assuming the same ratio of lift to port diameter in both cases. It is interesting to note that the smaller the valve the

lower the ratio of valve head mass to valve seat periphery, so that transference of heat from valve to cylinder head is facilitated with a smaller valve.

Fig. 13 shows the Bristol four-valve rocker mechanism and cylinder head, as used on the " Pegasus " and " Mercury " engines.

It is estimated that if two valves are to be retained, the swept volume of the cylinder should not exceed $1\frac{1}{2}$ litres ($91\frac{1}{2}$ cu. ins.) capacity, to maintain the necessary efficiency at the high crankshaft revolutions under discussion.

(ii) *Valve Mechanism*

A serious problem in connection with the proposed increase in engine speeds is the necessity for obtaining reliable operation from the valve mechanism. Push rod valve mechanism for air-cooled engines, which has been almost universally adopted during the last few years, and which is cheap to manufacture and light in weight, is, I am afraid, going to be quite inadequate for the engine speeds which I have suggested will be standard practice in the future.

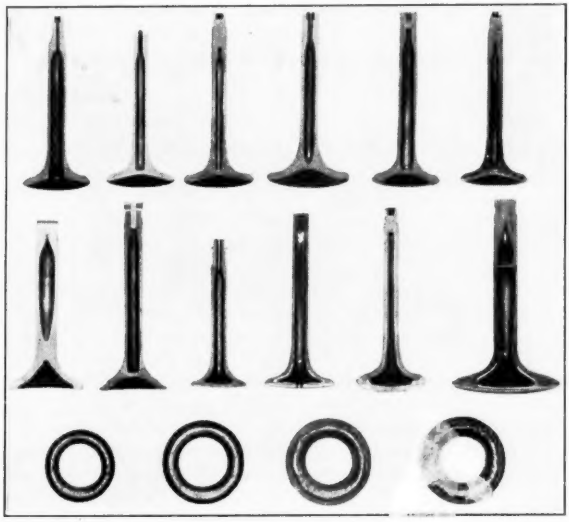


FIG. 14.

After extended development, reliable continuous running can be obtained from a four-valve, 3 litres (183 cu. ins.) capacity cylinder, with mechanical compensation to the push rod mechanism, up to 3,000 revolutions per minute, but even with these speeds the mechanical problems become very severe.

Adequate life of the mechanism may be preserved a stage further by the successful adaptation of the hydraulic tappet, the possibilities of which are now being explored by a number of engine manufacturers, but, to cope with the speeds required, I suggest the push rod operated valve must be dispensed with altogether. It is probable that the adoption of the overhead camshaft, with as nearly direct operation as is feasible, will be necessitated by further increases in engine speeds up to 4,000 revolutions per minute. Careful detail design, to obviate the blanking of cylinders and to eliminate oil leaks, will be necessary.

The only other alternative is to leave the poppet valve altogether, upon which more will be said later.

The question of seating velocity at elevated temperatures is also a matter of considerable moment, and this should not be greater than 1.5 feet per second, although this figure may be exceeded with sodium cooled valves.

To take proper advantage of the higher octane specifications referred to in Section (3), it will be necessary to stiffen the crankshaft and crankcase considerably, and to make a careful study of the technique of valves and valve seats originated by Mr. Heron, late of the R.A.E., Farnborough, and at present at the Matériel Division of the Air Corps at Wright Field, America. Recent developments in America have shown that it is fatal to expect continued high output on leaded fuels without making these modifications. Engines which have been satisfactory with leaded fuels at 14 to 16 h.p. per litre, have suffered severely when the output has been increased to 26 to 27 h.p. per litre. On civil engines where high continuous cruising h.p. has been taken, with even an 80 octane fuel and a comparatively low lead content, it has been found necessary to introduce such modifications to obviate rapid wear and deterioration.

To deal with the valve and valve seat problems, hollow valves with metallic sodium filling and special facings to the seats are necessary, and Fig. 14 shows

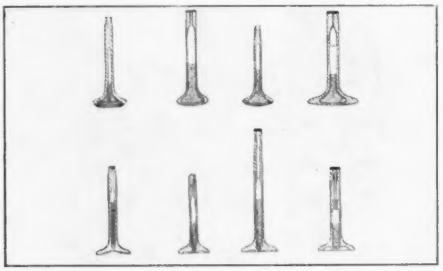


FIG. 15.

Representative Types of Salt-Cooled Valves.

examples of these valves and seats. Fig. 15 shows examples of the valves in diagrammatic form. These valves are a patented process of the Wilcox-Rich Corporation, Detroit, U.S.A., who have carried out a considerable amount of research over a wide range of types.

(iii) *Crankshaft and Bearings*

Increased engine speeds mean higher bearing loads. It is suggested, that by careful design, the strength and rigidity of the crankshaft can be maintained to meet the increase of rotational speed, but higher speeds and consequent greater pressures have already caused some difficulties with the white metals which have been standard practice on British aero engines up to the present time.

Development of harder bearing material, such as the family of steel-backed lead bronzes upon which considerable development has been achieved in America, will, I hope, be capable of coping with increased crankshaft rotational speed. The use of these harder bearing materials will, I suggest, necessitate the use of hardened crankshafts, although I understand that certain American firms have obtained satisfaction with unhardened shafts, but, speaking only from a limited experience, I should not care to change over to a lead bronze bearing on an unhardened shaft, in view of the average working conditions of our engines.

It has been suggested that further development is not possible because of high bearing loadings, but I do not think we have arrived at anything like the limits attainable. I believe that, provided lubrication and oil cleaning problems

are dealt with, one of the main factors of a big end bearing is the difference in hardness between the bearing metal and the shaft, and that when it is found necessary to increase the hardness of the bearing material to cope with increased loading, it will also be necessary to increase the hardness of the shaft.

For the crankshaft, the engine designer has the various alternatives of case-hardening alloy steel, nitrided steel of the nitralloy type, or nitriding chrome molybdenum steel. The Brinell hardness obtainable with the first and third types is about 650 to 750, while nitralloy offers a hardness of 800 to 1,100.

I believe that chrome molybdenum steel offers the best solution, owing to the freedom from difficulties experienced when case-hardening large diameter shafts. It is also preferable to the nitralloy steel, being a more satisfactory type with greater resistance to fatigue and giving freedom from the surface cracking sometimes experienced with the nitralloy type. Generally speaking, I believe the nitriding hardening process is preferable to case-hardening, for ease and regularity of production, when adequate hardening plant is provided.

For big end bearings, the most promising alternatives I suggest are steel-backed lead bronze, or the needle roller type. It would appear that the former is the most hopeful immediate solution, because the latter, although having many attractive points, presents difficult problems—especially in the larger sizes.

(iv) *Reduction Gear*

Increased rotational speed necessitates the adoption of airscrew reduction gear, if propeller efficiencies are to be maintained; and the use of reduction gears on high-powered engines has been general practice in England for the last few years. The Bristol Company, on their range of radial air-cooled engines, have not produced any ungeared engines for the past three years. In America the use of reduction gears has not been so widespread, and may, I think, be accounted for partly by the use of metal propellers, and partly because the large air-cooled engine has been developed with two-valve cylinders and high octane fuels, which have led to a type giving its power output from moderate revolutions and high brake mean effective pressure, rather than from moderate brake mean effective pressure and higher revolutions.

From the type of future engine outlined in this paper, the necessary power will be obtained by a combination of high brake mean effective pressure and high revolutions per minute, which will necessitate reduction gears being universally adopted, even on moderate power and smaller size engines.

Mr. B. Waseige, Technical Director of Messrs. Farman, France, has recently laid down that an efficient two-bladed airscrew should pass 3.35 lbs. of air per horse-power/second, whilst tip speeds ought not to exceed 820 feet per second for low altitude machines, and 980 feet per second for high altitude aircraft.

Concentric reduction gears are desirable for air-cooled radial engines to obviate air flow interferences, and the Farman bevel reduction gear, as standardised on Wright and Bristol engines, offers several advantages. The Farman type is very robust, gives considerable damping effect to the crankshaft system, and enables a wide range of propeller speed reduction to be obtained. With the increase of crankshaft rotational speed, reduction ratios of more than 2 to 1 will be necessary. Fig. 16 shows a selection of Bristol reduction gears for radial air-cooled engines.

(g) *Lubrication*

Since the introduction, by the British Air Ministry, of a straight mineral oil specification some three years ago, lubrication problems in England and America have been generally of a similar nature, except that I understand higher viscosity oils are used on air-cooled engines in America than are permitted in England. A number of European countries still adhere to vegetable base oils for aero engines, chiefly I believe for national reasons, but I think this practice is bound,

gradually, to fall into disuse—due to ring gumming and corrosion problems and the instability of such oils over prolonged periods.

There are two points I would like to touch upon, namely, oil consumption and sludging.

In an interesting paper on air-cooled aero engine design, read before the S.A.E. in America, by Mr. Philip Taylor, in April, 1931, an instructive curve was shown illustrating the consumption on air-cooled engines as being extremely critical, and suggesting that a rapid rise is reached after a certain engine speed. As already stated, I expect to see a considerable increase in revolutions per minute on future types of air-cooled engines, and this question of high oil consumption, from the point of view of the total weight of the power plant for a given range, is of the utmost importance to aircraft designers. Reduction in oil consumption

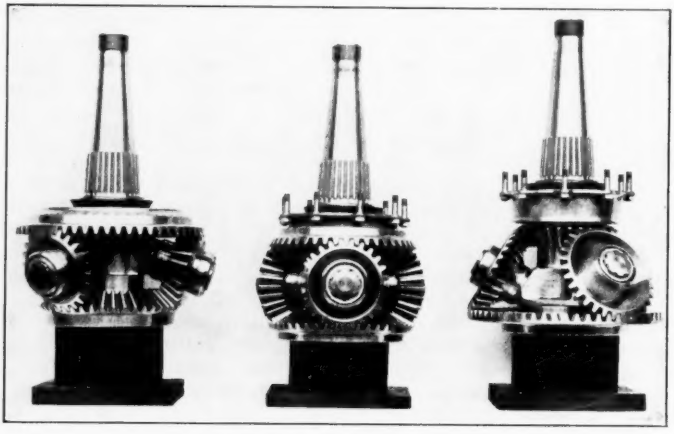


FIG. 16.

on the air-cooled radial engine is susceptible to treatment along several lines, such as: From the cylinder aspect, stiffer cylinder flanges, barrels and skirts; from the piston aspect, by suitable detail design modifications; and from the crankcase aspect by means of more efficient breathing and scavenging of the oil.

Oil temperature is also an important factor affecting oil consumption and sludging, and I suggest that we may hope that the oil technologists will, within a reasonable time, provide lubricating oils which may be employed with considerably higher temperatures and eliminate some of the sludging problems.

When one considers the extent to which the steam-cooled engine constructor is asking the aircraft designer to go in respect of bulk, weight, and expense, on leading edge coolers, it would appear that the air-cooled engine maker has every right to ask for a considerably larger capacity and more efficient low drag oil radiator than is at present standard practice.

Fig. 17 shows an attempt along these lines, which has given excellent results from the oil-cooling standpoint. Better oil straining and centrifuging is a logical request to make for high-speed air-cooled engines employing straight mineral oil.

(h) Compression-Ignition Engines

When reviewing the problems of fuel consumption of aircraft engines, certain aspects of the compression-ignition engine must inevitably present themselves.

The Bristol Company have been working on compression-ignition development for a number of years, on behalf and with the assistance of the British Air Ministry, but it is not possible here to go into details of the work that has been accomplished. It is sufficient to say, however, that some promising results have been obtained in England, particularly in regard to the fuel consumption of aircraft engines operating on this cycle; .360 lbs./brake horse-power/hr. can be obtained consistently at cruising powers with steady running and clean exhaust, and .39 lbs./brake horse-power/hr. at normal power, but this is not possible with as high a maximum brake mean effective pressure, or anything like as high a power/weight coefficient as with a petrol engine.

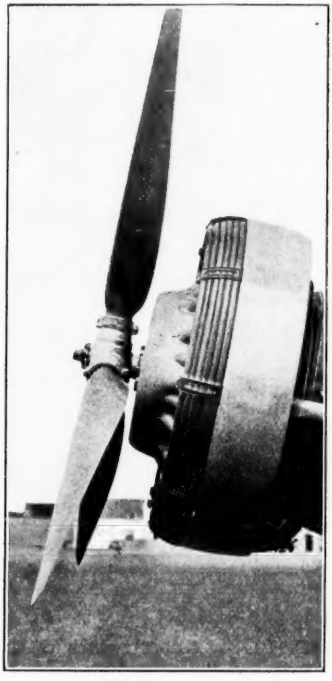


FIG. 17.

Some eight years ago the Bristol Company commenced development on a large four-cycle compression-ignition air-cooled single cylinder of $8\frac{1}{4}$ litres (503 cu. ins.) capacity (see Fig. 18). A number of different cylinders and pistons were developed, and promising results were ultimately obtained from this unit. Altogether over 2,000 hours' research work were carried out on this size of cylinder, with brake mean effective pressures in the neighbourhood of 90 to 100 and a consumption of less than .4lbs./brake horse-power/hr. Some three years ago it was decided that there was no immediate future for a large compression-ignition engine with cylinders of this capacity, and, in consequence, experimental work was commenced on a cylinder of the "Pegasus" size, *i.e.*, just over 3 litres (183 cu. ins.) capacity, embodying in it the results of previous experience.

The Bristol "Phœnix" engine, which has been developed by the Bristol Company as a result of this later experimental work, is of the nine-cylinder radial

air-cooled type, and of the same swept volume as the " Pegasus." This engine has completed 200 hours of bench testing and flying to date, and many thousands of hours of single-cylinder research work. Fig. 19 shows a view of this engine.

The flight reports obtained have been far beyond our expectations, and the bogey of Diesel " thump " has been entirely dismissed, the reports stating that the engine was comparable with a normal petrol engine as regards quality of running.

It is suggested that the power/weight ratio that has been obtained on the " Phœnix " engine is probably as good as can be expected for a four-cycle compression-ignition engine. The whole question of the weight of the compression-ignition engine is a problem which is continually engaging the attention of

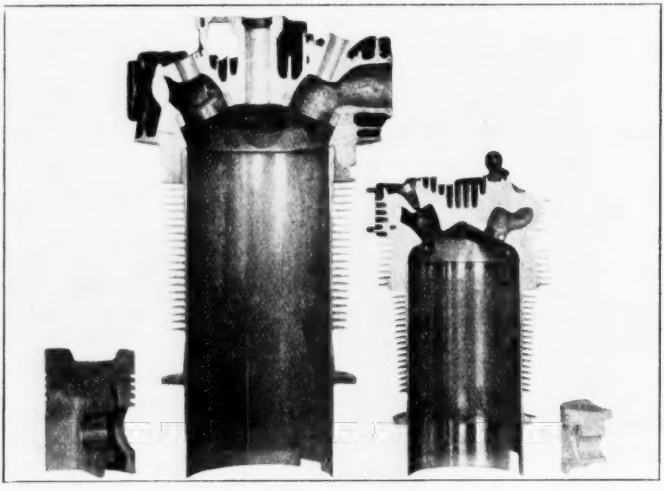


FIG. 18.

designers, and owing to the high maximum pressure involved, and, more particularly, the high rate of the pressure rise, engine components must be considerably heavier as compared with those of a petrol engine of equal power. I think it may safely be said that a successful air-cooled four-cycle compression-ignition engine will weigh 30 to 40 per cent. more than its petrol engine counterpart, but will have a cruising consumption 30 per cent. less than a corresponding petrol engine.

Throughout their experience, the Bristol Company have adhered to a maximum pressure of 850 lbs./sq. in., and have employed standard Navy fuel oil of 0.870 specific gravity, and of a specification readily obtainable all over the world.

Prior to the flight tests on the Bristol " Phœnix " engine, it was thought that this increased weight would be a serious obstacle to the extensive use of compression-ignition engines, until such time as aircraft were regularly operated on longer non-stop stages than at present, but that such engines would give considerable advantage in weight-carrying capacity on long flights in excess of six to eight hours. The flight tests referred to, however, have shown that the power maintenance factor at altitude, with the compression-ignition engine, falls off much more slowly than that for the petrol engine, to such a degree in fact that it is suggested that the four-cycle compression-ignition engine will show an

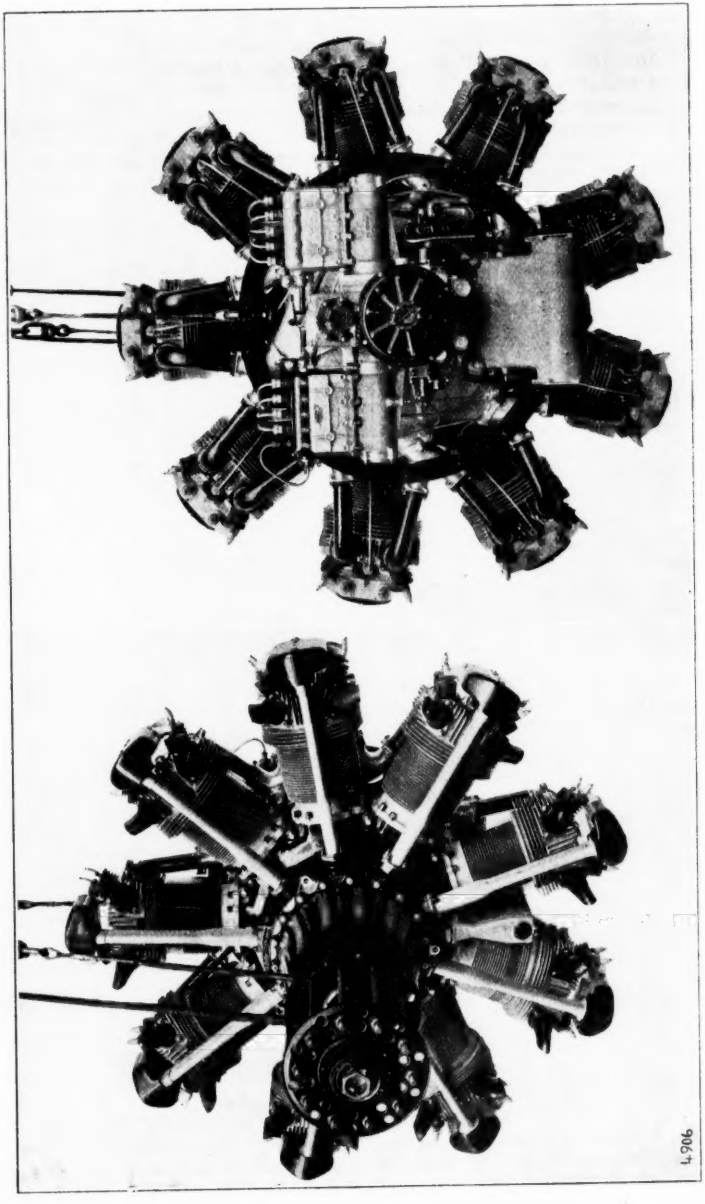


FIG. 19.

advantage in all-up weight on a flight of four hours' duration, when the cruising range is considered at a height of approximately 10,000 feet.

Fig. 20, shown by the courtesy of the Westland Company, illustrates this point.

One of the greatest obstacles to the use of the compression-ignition engine has been the inability to obtain a high brake mean effective pressure for take-off without increasing the fuel charge to a point resultant in a foul exhaust. Single-cylinder research work has proved that supercharging will assist this problem and will provide a four-cycle compression-ignition engine such as the "Phœnix" with sufficient power for take-off to make the engine a commercial possibility.

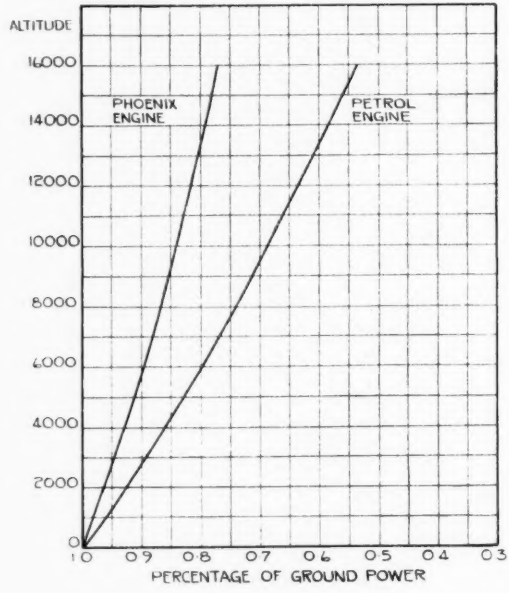


FIG. 20.

Relative power maintenance at altitude on unsupercharged engines.
(1) *Phœnix engine curve based on Westland Aircraft Co.'s flight test data.*
(2) *Petrol engine curve based on standard Air Ministry correction factor, Ref. A.P. 840, Addendum B.*

It is, of course, obvious that the advantages of the compression-ignition engine, from the aspect of fuel consumption, are further reduced by every step-up in octane value of standard fuels, while its claims from the aspect of fire risk are also somewhat nullified by the use of a high flash point hydrogenated fuel which may be used with the direct fuel-injection engine.

I do not visualise compression-ignition engines being used for light sports aircraft, single-seater fighters, or high-performance general purpose military aircraft during the period under review, as, although sufficient cruising power can be obtained, there is no doubt that the modern high-speed, high output petrol engine, using a high octane fuel, can provide take-off powers which cannot be approached with the four-cycle compression-ignition engine. I suggest, however, that, during the period under review, the four-cycle compression-ignition engine

may mature in moderate sizes for certain military and civil purposes, such as army co-operation and mail-carrying work, where fuel consumption and the quality of fuel, due to the operating regions, are governing factors, and that we may see the development of a large compression-ignition engine of considerable volume specially applicable to large flying boats.

(*i*) *Direct Petrol Injection*

I well remember the first direct petrol injection engine that I ever saw—early in 1911—on the " Antoinette " monoplane, belonging to the well-known pilot, Latham. It was an eight-cylinder " Levavasseur " engine with several interesting features, including condenser cooling. I am of the opinion that direct petrol injection lost ground, and finally disappeared in those early days because of lack of technique in manufacture, and because the line of least resistance was to make use of the carburettor, upon which so much more development had been carried out on the motor car. Of recent years, interest has been revived in direct petrol injection for aviation engines, and a considerable amount of development work has been accomplished on these lines in America.

Experimental work has been carried out by the Bristol Company and the Westland Company on the test bench and in the air, on direct petrol injection, on behalf of the British Air Ministry, but at the present time I am not at liberty to give details of the design of the fuel injector system employed.

It would appear that the claims of better distribution would be more apparent, for this system, on an in-line engine, than on the radial, which is quite satisfactory in this respect already.

There seems little to choose on weight and, although it is agreed that the modern aircraft carburettor has become quite a precision piece of mechanism, one cannot feel that there is anything to be scored on the grounds of simplicity or cost with direct petrol injection.

Two important factors in favour of direct fuel injection are—elimination of freezing, and the ability of this system to use hydrogenated fuels, with high knock ratings, which cannot be carburated owing to their low volatility. Freezing is certainly a serious problem when flying with a throttled, highly supercharged engine in an atmosphere of high humidity. If this problem of freezing cannot be dealt with with a normal carburettor, which hardly seems to be a reasonable assumption, then direct petrol injection must undoubtedly be pursued. Tests to date have been quite promising, and I understand from the Westland Company's reports that freezing problems have been entirely eliminated, but it would seem that further development and simplification are desirable before putting such a system into production, and one cannot help feeling that had the problem been reversed, and we had been brought up to consider direct petrol injection as the standard equipment, we should hail the carburettor as a simpler solution. This view is not held in America, and direct petrol injection is being developed on a high priority, and a live interest is being taken on its adaptation in a number of different types of aircraft. A number of civil twin-engined aircraft have been operating with this system for some months past, with complete success, and it is suggested that further consideration must be given to this matter before any final decision can be arrived at.

(*j*) *Two-Stroke Engines*

I do not expect to see very serious competition from the two-cycle principle during the next ten to fifteen years, except in conjunction with a compression ignition or Diesel type of engine. Personally, I do not view the possibilities of the normal two-stroke petrol engine favourably, owing to cooling problems, low efficiency, fuel wastage, etc., although I suggest that a supercharged direct petrol injection version of the two-stroke engine, in the smaller sizes, might conceivably

possess advantages worth exploiting, as the scavenging could be achieved with air only, and fuel wastage reduced. In an attempt to attain efficiency, many projected two-stroke engines have gradually become more complicated than their four-stroke competitors, and thus one of the chief attractions of the two-stroke engine has been lost.

One of the most serious problems on the air-cooled two-stroke engine is that of cooling, and on some of the designs recently submitted to my firm for criticism, cooling difficulties have been the governing factor which has prevented the proposition being attractive.

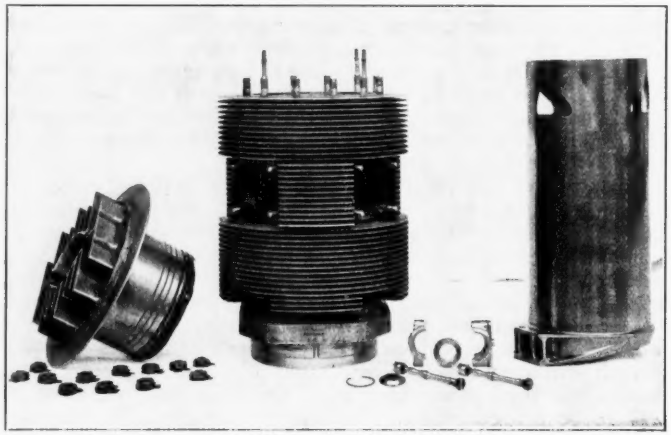


FIG. 21.

(*k*) *Sleeve Valve Mechanism*

I am one of those who believe that the poppet valve is still with us, because of the immense amount of development work that has been devoted to it. Even so, with the trend of design of aircraft engines, the poppet valve and its seat are steadily becoming more expensive and complicated, as already outlined in this paper, and I believe that if only the same development had been given to some other system such as, for example, the sleeve valve, our engines to-day would be of superior performance and cheaper manufacture.

The sleeve valve, and particularly the single sleeve of Burt McCollum type, offers a number of advantages not possessed by the poppet valve. These have been reviewed so many times that it is sufficient to mention only three:—

(*a*) Simplicity.
(*b*) Absence of hot spots on the combustion chamber.
(*c*) Excellent valve diagrams facilitated by the rapid opening and cut-off obtainable.

During the last six years the Bristol Company have carried out an extensive research on the single sleeve valve for air-cooled aero engines, on behalf, and with the collaboration, of the British Air Ministry. Some seventeen hundred hours have been completed on a single cylinder unit, and Fig 21 shows one of the cylinders used on this single cylinder development.

Recently a complete nine-cylinder sleeve valve radial air-cooled engine, called the " Perseus," was submitted to an entirely satisfactory hundred hours' official type test, and Fig. 22 shows a view of this engine. Subsequently a fifty hours'

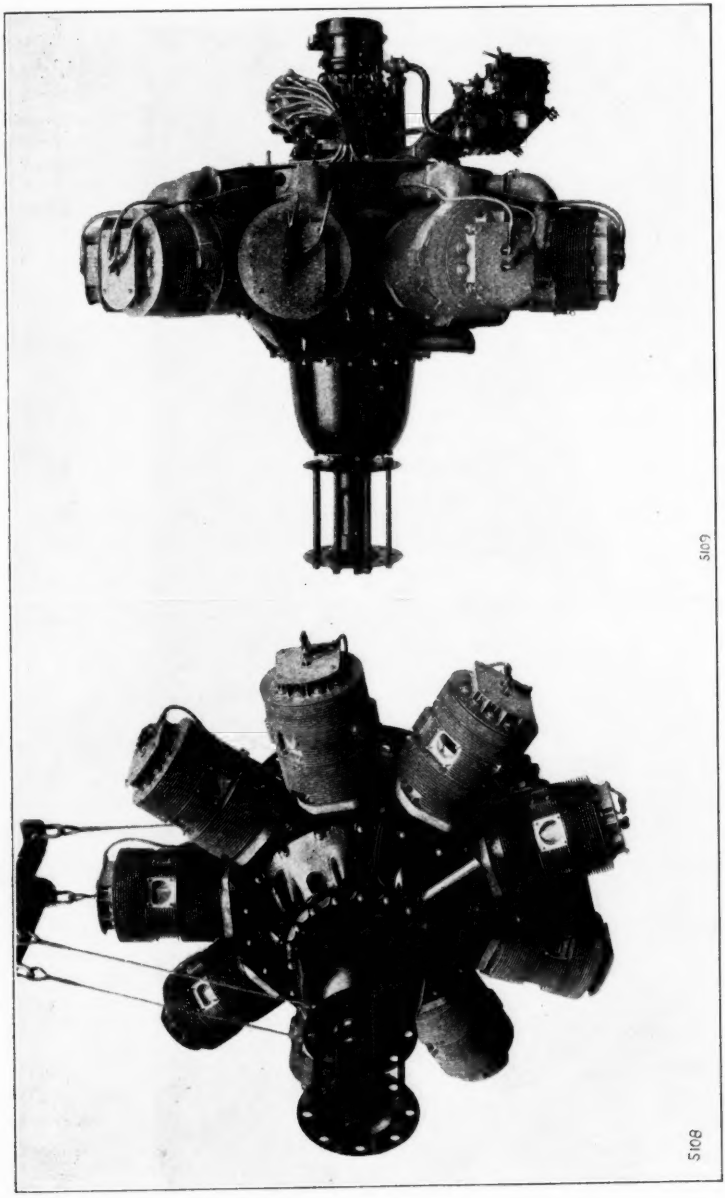


FIG. 22.

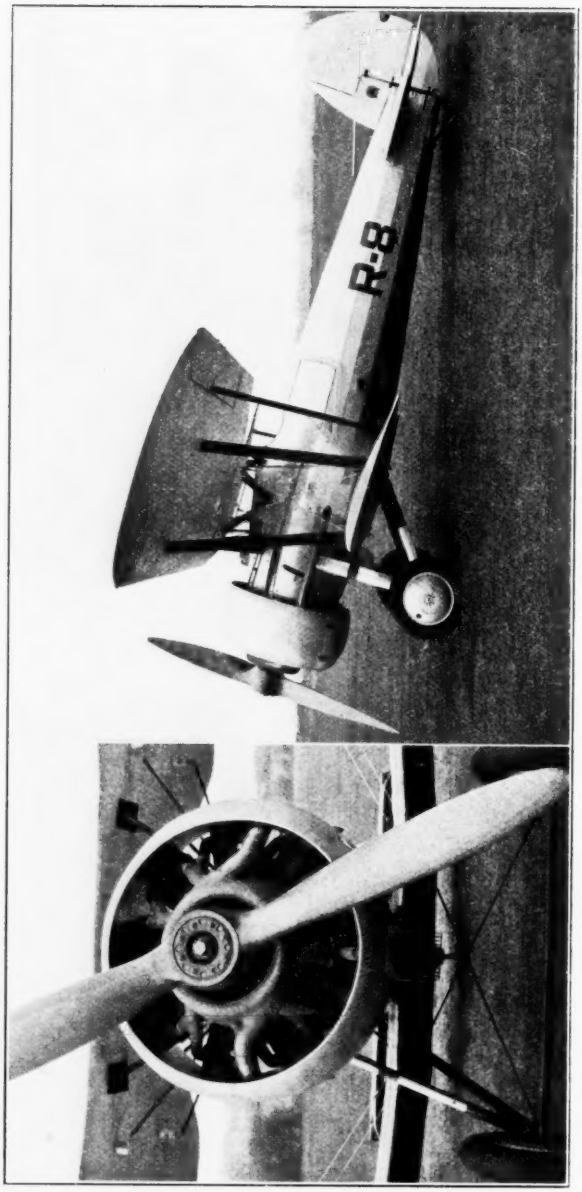


FIG. 23.

The "Bristol" Perseus sleeve valve engine installed in "Bristol" Bulldog.

high power test followed by a fifty hours' weak mixture test, were successfully completed with the same engine, and it is at present undergoing flight test in an aircraft.

Fig. 23 shows a view of the " Bulldog " with " Perseus " engine.

At the present time it is not permissible to go into the technical details of this engine, but it is interesting to note that the test was carried out without any maintenance or adjustment, and without removing the sparking plugs, during the whole of the test, and with a lower fuel and oil consumption than we have ever achieved on a poppet valve engine of similar layout.

As a result of this development work on the single sleeve valve for air-cooled aero engines, it is considered that:—

(1) Greater all-round thermal efficiency can be obtained than with the overhead poppet valve.
(2) That for a given cylinder capacity, approximately one compression ratio higher can be used, with the sleeve valve, than with the overhead poppet valve, with any given octane number fuel.
(3) Correspondingly, in case of emergency, a lower grade of fuel can be used, with any given compression ratio, than with the poppet valve engine.
(4) Lower fuel and oil consumptions have been obtained than with the corresponding poppet valve type.
(5) Lower cost of manufacture than with the corresponding poppet valve type.
(6) Greater scope for large production with unskilled labour.
(7) Materials are more easily obtained.
(8) Lower maintenance costs.
(9) It is more able to stand ground boosting, and more easily adaptable to higher rates of supercharge, than with the corresponding poppet valve engine.
(10) Cooling and cowling problems are simpler.
(11) Deleterious effects from leaded fuels would appear to be less apparent than with the poppet valve engine.
(12) Lower exhaust ring temperatures, combined with sleeve valve operation, minimise fire risk.

It is suggested that there is an important future for this type of valve operation for the air-cooled aero engine, and the complete absence of normal maintenance work makes it attractive for civil work.

(i) *Obtaining the Maximum Thrust Efficiency from Available Brake Horse-Power*

It has been claimed for some time past that an improved take-off and cruising range could be obtained from existing aircraft power plant if some means of altering the propeller shaft gear ratio or changing the pitch of the propeller itself, could be effected at will by the pilot, while in flight, and the theoretical sides of these two problems have been ably dealt with by Mr. W. B. Jennings, at the Royal Aeronautical Society on November 2nd, 1933.

I realise that this problem does not strictly come within the purview of this paper, because it is aerodynamic rather than thermodynamic, but I propose touching on the mechanical side, as I hold the view that, if adequate reasons exist for either or both of these changes being introduced into the power transmission section of an aircraft, they have been far too long coming into fruition, and that one of the most important directions in which they can be speeded up is by the aircraft designer instructing the engine maker as to his requirements aerodynamically, and then letting the engine maker endeavour to develop the device from a mechanical standpoint. Up to the present time these problems

have lain in " no man's land " between the aircraft and engine sides, hence some of the long-drawn-out agony of their development, and I submit that until such devices are built into the power plant and made " part and parcel " of the engine design, a practical solution is not likely to be obtained.

The above remarks apply more aptly to Europe than to America where a combination of aircraft and engine has been developed, which enables the efficient use of the controllable pitch propeller to be made, and where this device has actually been brought to fruition on the lines which I suggest are the only practical solution of the problem. A number of variable pitch propellers are at the present time in daily use on military and civil aircraft, and their employment will be widely extended within the next few months.

The problem can be divided into two classes—(*a*) multi-speed gear, and (*b*) variable pitch propeller.

(*a*) While, at one time, I had hoped that the multi-speed gear would be worth while on such types of heavily loaded aircraft as flying boats, etc., where take-off is extremely critical, even though it might not be the ultimate solution, an investigation into the possible improvements in performance, with a multi-speed gear and supercharged engine, showed a disappointing increase in thrust horse-power for take-off, and different gear ratios would be required for varying installations. The weight of the two-speed and operating gear would be of the order of 50lbs. for an engine of 600 to 700 h.p., and, after further consideration, the variable pitch propeller seemed to offer so many more advantages that it was decided not to proceed with the solution of the multi-speed gear.

(*b*) Propellers whose pitch may be altered while in flight may be divided into four main types, and, omitting the blades, it would appear, in the present state of development, that the weight of the hub, complete with its controllable mechanism, for an engine of 600 to 700 h.p. is of the order of 100lbs.

The four main types are as follows:—

(1) *Automatic Type*

In this type no pilot's control is provided, and the pitch of the blades may depend on either the speed or power transmitted, or on a combination of both. This type possesses a serious disadvantage, inasmuch as it does not permit of the most economical cruising, together with good take-off, as the laws governing these two cases are incompatible.

(2) *Manual Controllable Type*

This type is one in which movement of the pilot's control causes continuous alteration of the pitch. Airscrews of this type can provide both good take-off and low engine speed when cruising, but necessitate the pilot constantly attending to yet another control. The present production edition of the Hamilton V.P. airscrew is a variant of this type, in which the range of pitch angle variation is restricted to two values only, the choice of high or low pitch positions being under the pilot's control.

(3) *Governed Pitch Type*

This consists of a controllable pitch airscrew fitted with a suitable follow up mechanism. It enables the pilot's control to be graduated, and it is possible for his lever to be set immediately at a desired pitch, whereupon the follow up mechanism causes the blades to assume this pitch gradually and maintain it.

(4) *Governed Speed Type*

Here the pilot's control permits adjustment to any engine speed within the operating range, this speed being subsequently maintained by some governing device. This, I suggest, is the best type of variable pitch mechanism, inasmuch

as it relieves the pilot of all responsibility, even in aerobatics, and minimises any tendency to run the engine beyond maximum crankshaft speed.

Assuming that aircraft, which can make efficient use of controllable pitch propellers, will come into being within the period under review, I suggest that the controllable hub mechanism will be an important development for the engine constructor, and that the most promising solution lies in the controllable speed type. At the same time such a propeller would undoubtedly give the engine a hard time, though I feel that this problem must be faced by engine designers.

The conditions imposed on the engine by the use of the variable pitch propeller will be more severe than those extant at the moment, especially on the air-cooled engine, and further development will be necessary to enable engines to stand up satisfactorily to the more arduous conditions.

In view of the conditions just outlined, I feel that type test conditions will have to be modified, and it is possible that engine ratings will have to be reviewed.

(*m*) *Development of Aircraft Engine Material*

Owing to economic conditions and the comparatively small output, the British aero engine constructor is, at the present time, at a serious disadvantage, as compared with certain other countries, in regard to the technique and quality of raw materials for the manufacture of his engine, and this is a serious handicap which it is hoped may be remedied as soon as is feasible.

Dealing firstly with ferrous alloys, perhaps more important than anything else is the cleanliness of aero engine steel. I think steel makers in England during the last few years have realised the importance of this fact to aero engine manufacturers, and some work is being done along the lines of improving the manufacture of steel for aircraft engine purposes, but enough has not yet been accomplished.

Suitable hardening of highly-stressed parts increases the fatigue range, and chrome molybdenum steel nitrogen hardened, as referred to in a previous section of this paper, has an extremely good fatigue range.

The line of air-cooled aero engine development that I have advocated demands a stiffly-made structure; I am also a strong believer in hardened parts wherever possible, and think we may see the introduction of a considerable amount of chrome molybdenum hardened alloy steel in future aero engine construction. I favour this material rather than the aluminium nitralloy steel, excepting perhaps for small parts.

In the continual search for means whereby to reduce the weight per horsepower of aircraft engines, much research work has been carried out on light alloys, with varying results. I am in favour of light alloy forgings for aircraft engines, and hope to see the day when castings are eliminated from all stressed light alloy parts. The Bristol Company were the first makers of aero engines to employ forged crankcases and forged cylinder heads, and, at the present time, in addition to these components, all their engines have forged reduction gear housings, pistons, and a number of other small components, that are made from forgings.

In assessing the value of non-ferrous light alloys for aircraft engines, it is important to consider their strength and stability at elevated temperatures, because it is easy to be led astray if the physical properties of the material are considered only at normal temperatures.

When selecting a light alloy material for aero engine design, it is suggested that it is important to consider the creep stress of the material concerned, and some valuable research work along these lines is being carried out at the National Physical Laboratory, and High Duty Alloys, Ltd.

Amongst light alloys, those of magnesium naturally assume a prominent position, owing to their extremely low specific gravity, which is of the order of 1.8 as compared with 2.8 of the aluminium base alloys of the duralumin family.

A tabulation of the physical properties of cast and forged magnesium alloys, in comparison with two of the well-known R.R. series, is shown in Fig. 24.

MAGNESIUM AND ALUMINIUM ALLOYS.
COMPARATIVE PHYSICAL PROPERTIES.

Alloy.	Specific Gravity.	Proof Stress tons sq. in.	Modulus of Elacticity.	Maximum Stress tons sq. in.	Elongation %.	Brinell Hardness.	*Approx. Creep Strength lbs. sq. in at 250 °C.
Cast magnesium alloy.	1.80	5 to 6	6.2×10^6	12 (Min.)	6.0 (Min.)	45—60	425
Cast copper aluminium alloy.	2.80	10	10.5×10^6	12.5 (Min.)	4.0 (Min.)	60—80	4500
Forged magnesium alloy.	1.82	8 to 10	6.5×10^6	15 (Min.)	5.0 (Min.)	65—70	540
Forged copper aluminium alloy.	2.80	22	10.5×10^6	27 (Min.)	10.0 (Min.)	120—160	5600

* Stress corresponding with creep rate at the end of 40 days of one hundred thousandth of an inch per inch per day.

FIG. 24.

There are at present certain manufacturing difficulties associated with these magnesium alloys, and, during the early days of their development, trouble was experienced with oxidation during casting and forging, but this defect has, I understand, been overcome.

The results obtained with cast magnesium alloys, where scantlings are cut, are disappointing, and, in certain circumstances where stiffness is not essential, it has been found possible to produce as light or lighter castings in aluminium alloy than in magnesium alloy. On certain other parts of the engine where stiffness demands a fairly good section, such as the rear cover, blower casing, etc., magnesium can be used with success. It is, however, still difficult to forge, and pressing would seem to be the most promising solution, as too vigorous forging has, I understand, a detrimental effect on the crystallographic structure.

The Bristol Company have not had success with magnesium forgings for crankcases. No actual failures have occurred, but distortion, flaking on the faces, loosening of studs, etc., have clearly brought out the very low strength of this material at elevated temperatures.

While these alloys can be usefully employed in some components, the weight saving effected in highly-stressed parts is small, as, owing to their low proof stress and modulus of elasticity, the component is sometimes subject to permanent deformation. The Brinell hardness possessed by these magnesium alloys is also low compared with aluminium base alloys, especially at elevated temperatures, and the heat conductivity is considerably lower than that of the aluminium base type, so that they are not profitable at present for use on cylinder heads and pistons. Progress is being made, however, with heat-treated alloys having mechanical properties more nearly approaching aluminium base alloys.

Magnesium possesses one important advantage when used for small housings of auxiliary drives, inasmuch as it provides better bearing qualities than duralumin, and hardened shafts may be run in it without bushes.

A considerable amount of research work is going on with magnesium alloys, and, seeing the unbounded available supplies of this material, I suggest that we may reasonably expect to see a considerable advance in the physical properties of

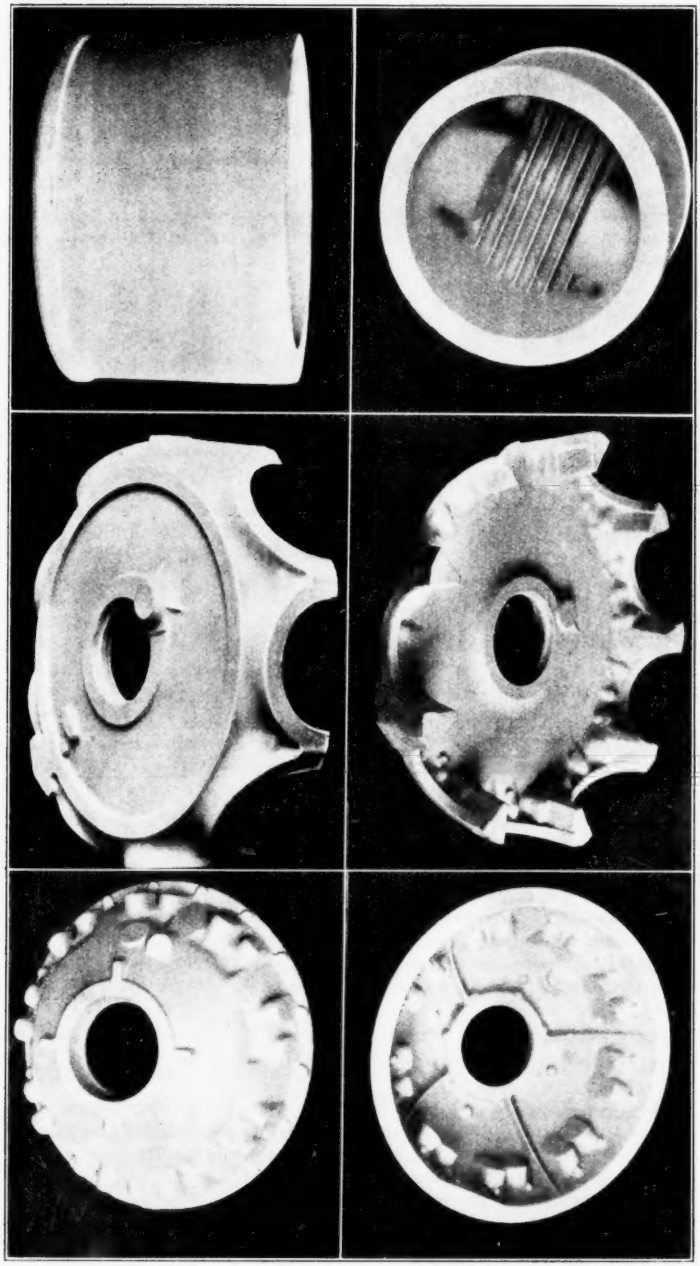


FIG. 25.

Typical examples of American aero engine light alloy forgings.

magnesium alloys during the period under review, together with improved technique in the manufacture of forgings and their employment in aero engine manufacture.

Another metal which is attracting some attention at the moment is beryllium, the specific gravity of which is a little higher than magnesium alloy, namely 1.93. Although brittle, it has the attractive quality of being extremely hard and having the very high melting point of 1,278 degrees centigrade, as against the 658 degrees centigrade of aluminium.

The commercial supply of beryllium is at present on nothing like the same scale as magnesium, hence even when the technical difficulties are cleared away, I understand we are not likely to be able to look upon this material seriously for aero engine manufacture.

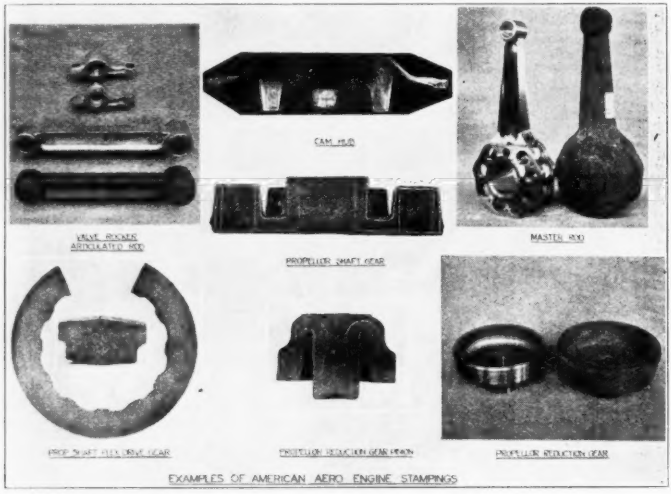


FIG. 26.

When alloyed in small quantities with certain heavier materials, such as copper, however, it gives remarkable hardening qualities, together with increased resistance to corrosion, and it is along these lines that it is hoped we may expect value from beryllium during the period under review.

Fig. 25 shows typical examples of American light alloy aero engine forgings, and Fig. 26 examples of American steel stampings.

SECTION IV.

SUMMARISATION OF IMPORTANT FACTORS GOVERNING AIRCRAFT ENGINE DESIGN

To sum up, therefore, I suggest that the most important factors governing the development of air-cooled aero engines, during the ten to fifteen years period under review, fall under the following headings:—

(1) That, short of some entirely quite revolutionary discovery, the bulk of aero engines for sport, civil work, and for general purpose military aircraft, will remain electric-ignition petrol engines of the four-cycle type, retaining pistons, cranks, and connecting rods.

(2) That better quality fuels will be employed on aircraft engines, permitting increase in compression ratio, brake mean effective pressure, and improved fuel economy.

(3) That present-day engines will be looked upon as bulky, cumbersome, and altogether too large for their power output, and that just as to-day a full-size touring car is doing better work with an engine of half the swept volume of the corresponding vehicle of fifteen years ago, so we shall find that aircraft will be putting up improved performances with engines of considerably less swept volume than those which are employed to-day.

(4) That all aircraft engines, even of the sports type, may employ some sort of blower. Military engines will use a high supercharge to restore and maintain power to considerable heights, while civil engines will use a blower of lesser compression ratio to restore normal power to moderate heights.

Military aircraft, requiring engines maintaining power to a considerable altitude, will eventually have to use a multi-stage centrifugal blower with inter-coolers, and, if this does not " fill the bill," we may go back to the exhaust turbo compressor, but, with the recently introduced enrichening device for take-off, the present rate of supercharge, giving a rated altitude of 15,000 feet, may suffice for some considerable period, as it is quite possible that it will be found that the present supercharged military engine is ahead of some of the equipment of the aircraft.

(5) That with an increase in efficiency of aircraft engines, and the general use of supercharging, important alterations and developments will be required in cylinder and piston design.

(6) To meet the demand of output from a smaller volume, it will be necessary to increase considerably the crankshaft rotational speed, and modifications will have to be made in the design of crankshaft, bearings, and valve mechanism, while there is a possibility of the poppet valve being superseded altogether. If, however, the poppet valve is retained, additional technique and expense will have to be incorporated into the manufacture of this component.

(7) That all engines, except possibly those of the smallest type, will be fitted with reduction gearing to the propeller shaft, and, to maintain propeller efficiency with high crankshaft rotational speeds, the higher powered engines will employ ratios greater than 2 : 1.

(8) That for certain types of aircraft a variable-pitch propeller will be standardised during the period under review. The controlled speed type is favoured, but it is desirable, to achieve practical results, that this device should be incorporated and built into the design of the engine.

(9) That the general tendency of military engine design demands a more severe type test procedure than at present, and than an appreciable period of the type test should be occupied in running at maximum revolutions, and in excess of maximum revolutions. The civil type tests should be run continuously at maximum revolutions.

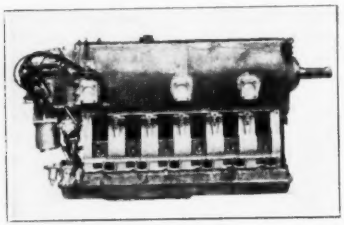
(10) That within the period under review, the necessity will arise for a much larger aircraft power unit, and that when this matures it may be of the compression-ignition type.

I will endeavour to tabulate the most useful types of aircraft power plant, as follows; and I would like to say a few words on each—

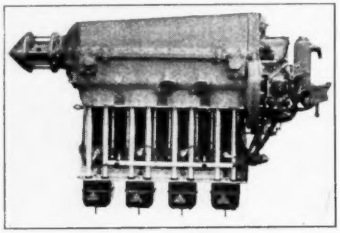
(*a*) Sports and training—light type engine.
(*b*) Small civil type engine.
(*c*) Intermediate civil and military type engine.
(*d*) Current type military and air liner engine.
(*e*) High power high efficiency military type engine.
(*f*) Large flying boat and large air liner type engine.

Category (a)—Light type Engine

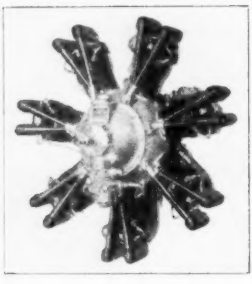
For this type of engine air cooling is supreme, and I suggest that it will remain so. The question of price is of paramount importance. Owing to a combination of factors such as ease of production, low first cost and maintenance, ease of cooling of small cylinders, narrow bodies, etc., the four-cylinder in-line engine up to 130 h.p. seems to be the most suitable compromise, and has given every satisfaction in service.



Napier "Javelin," 155 h.h.p.



"Gipsy Major."



The 7-Cylinder "Genet Major" Engine.

FIG. 27.

Fig. 27 shows a composite picture of the four-cylinder 130 h.p. inverted "Gipsy Major," the 140 h.p. seven-cylinder Armstrong-Siddeley "Genet Major," and the six-cylinder in-line Napier "Javelin" of 155 h.p. The first two are well-known production types, while the "Javelin" engine recently introduced by the Napier Company embodies some interesting and up-to-date features for air-cooled in-line engines, such as overhead camshaft, modern cylinder finning, etc.

For several reasons the six-cylinder engine is extremely attractive when considering the high power end of the scale of this category, and, undoubtedly, this type of engine has a future in certain specialised types of aircraft, but, seeing that we are discussing the very cheapest aircraft power unit possible, and considering the extra length and weight of the crankshaft and crankcase, I suggest that it is doubtful if the weight and cost of this type can be afforded for general use. I think, therefore, that we shall see the four-cylinder in-line a healthy competitor in this class for some time to come, and that when it is necessary to increase the power, I am in favour of the radial as typified by the Armstrong-Siddeley "Genet Major."

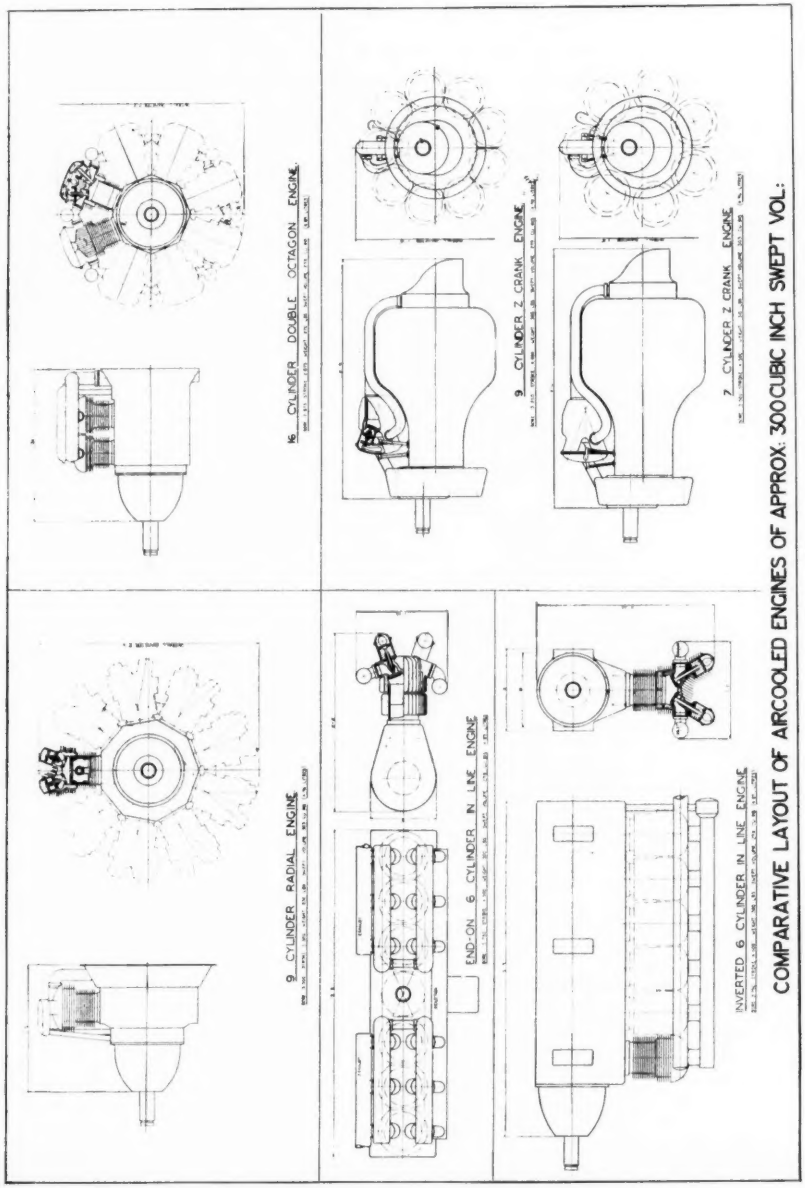

16 CYLINDER DOUBLE OCTAGON ENGINE
9 CYLINDER Z CRANK ENGINE
7 CYLINDER Z CRANK ENGINE
9 CYLINDER RADIAL ENGINE
END-ON 6 CYLINDER IN LINE ENGINE
INVERTED 6 CYLINDER IN LINE ENGINE
COMPARATIVE LAYOUT OF AIRCOOLED ENGINES OF APPROX. 300 CUBIC INCH SWEPT VOL:

FIG. 28.

The average capacity of this category of engine, at the present time, is approximately 6 to 7 litres (366 to 427 cu. ins.), and I suggest that we should aim at reducing this by 25 per cent.

In this category, where prime cost is of such vital importance, I expect to see some determined efforts made to break new ground, and it would appear that the two-stroke direct petrol-injection engine might prove a possible solution.

Category (b) —Small Civil type Engine

There seems to be some interest in Europe in the small economical twin-engined passenger machine, carrying eight to ten passengers, and, if this type of civil aircraft becomes popular, the civil engine of 200 to 225 h.p. will become an important category. It may also be used for training purposes. I believe it will be air-cooled, and I suggest that the best solution will be a nine-cylinder radial.

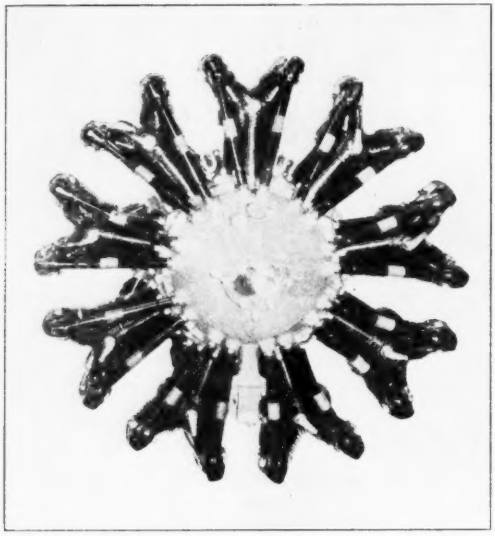


FIG. 29.

Some two years ago the Bristol Company investigated such a type of engine, and Fig. 28 shows the layout of the types reviewed.

(1) The nine-cylinder air-cooled radial.
(2) The 16-cylinder double octagon engine.
(3) The six-cylinder inverted engine.
(4) The six-cylinder horizontal engine for fitting into the leading edge of a thick wing.
(5) The seven-cylinder " Z " crank engine.
(6) The nine-cylinder " Z " crank engine.

Quarter scale models of these engines were made and investigated by Captain Barnwell in the Bristol Company's wind tunnel, from the point of view of drag, mounting, cowling, accessibility of installation, etc., while the Company's engine department looked into the design of these six engines, cooling possibilities, weight, cost of manufacture, etc.

Taking into consideration all factors, the nine-cylinder single bank radial proved the most promising solution. It is worth noting that the " end on " six-cylinder engine, so much discussed on the continent at one time, as a low drag type, proved to be unsatisfactory owing to wing interference.

I suggest that this category of engine may prove a useful type, and should be of 5 to 6 litres (305 to 366 cu. ins.) capacity.

Category (c)—Intermediate Civil and Military type Engine

This category of engine of approximately 300 to 400 horse-power, and 15 litres (915 cu. ins.) capacity, has, in the past, been mainly employed for civil work, and will, I suggest, continue to hold a prominent position in this field, but with the possible introduction of a high performance twin-engine fighter aircraft, this engine may prove an important military category in high efficiency form with gearing and supercharging. Up to the present time the single bank air-cooled radial has proved the most satisfactory type, and I suggest that the nine-cylinder radial offers the most promising solution for the future.

The advantages of the single bank radial in regard to simplicity of manufacture, accessibility, maintenance, cooling, stiffness, light weight, etc., afford, in my opinion, definite advantages over and above the multi-bank type.

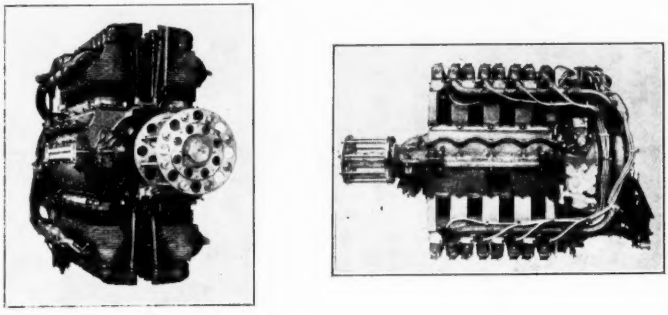


FIG. 30.
Napier " Rapier," 305 b.h.p.

Fig. 29 shows a view of the Pratt and Whitney " Wasp Junior," which is a fine example of this type of engine.

In this category I suggest that we shall see the swept volume reduced to about 8 to 9 litres (488 to 549 cu. ins.), a considerable increase in rotational speed of the crankshaft, a change in the valve operating mechanism, and the introduction of airscrew reduction gearing.

Fig. 30 shows two views of the Napier " Rapier " 16-cylinder four-bank in-line air-cooled engine, typical of this latter class. This engine, designed by Major Halford, is an extremely interesting type, and is, I believe, the first effort to produce a high performance air-cooled engine running at high revolutions per minute, and with considerable output per unit volume.

I consider we may expect the military rating of this category raised above 400, and seeing that the engine capacity for the Coupe Deutsch de la Meurthe, an important bi-annual continental race, is 8 litres (488 cu. ins.), I expect to see considerable development in this category.

Category (d)—Current type Military and Air Liner Engine

Under this heading—current type military and air liner engine—I suggest that the air-cooled engine will continue to have a wide field of operation.

Fig. 31 shows an example of the Bristol " Pegasus " engine by the side of the American Wright " Cyclone " engine, shown for the first time in Europe at the Paris Salon last December.

I fear that my audience may feel that I am somewhat prejudiced towards the nine-cylinder air-cooled radial engine. This is almost unavoidable, but I am convinced there is a great deal in favour of this engine, and that it will still have a considerable life in the aviation world. For a given volume, I believe it to be lighter and more easily cooled than the multi-row engine. For a given weight it can be made stiffer in construction; it should be better from a production and maintenance standpoint, simpler to cowl and to arrange with an efficient exhaust manifold system, while the machine gun clearance on a single-engined aircraft can be more easily provided; and, although I realise that as powers increase, more than one row must be faced for the large air-cooled radial engine, I recommend that the single row radial is retained as long as possible, and that the number of rows of cylinders should be kept down as low as possible.

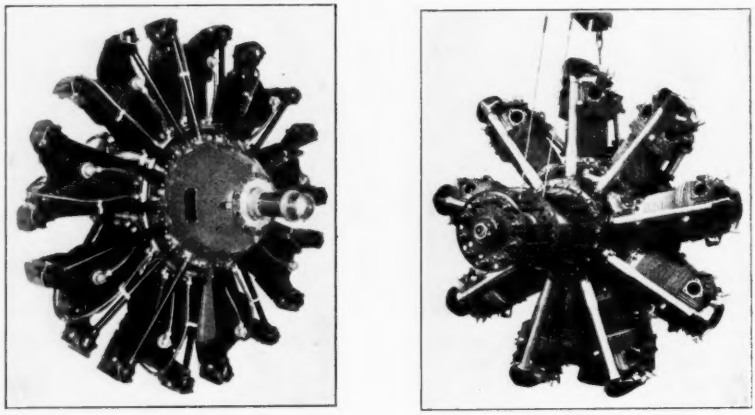


FIG. 31.

¾ Front View of Wright Cyclone Gir-1820-F.

Distribution should be easier with the single bank type and, with the increase of speed that has already been satisfactorily achieved, any previous difficulties of torque recoil have been eliminated at the powers of this category.

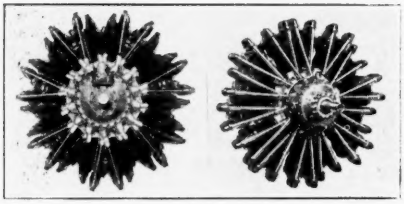
The American engine made an excellent impression at the last Paris Salon, and a comparison of the English and American train of thought, with these two identically similar types, is worth noting. The English engine is of smaller capacity than the American by about 1.2 litres (73 cu. ins.) and the power and specific weight, based on a similar octane value fuel, are approximately the same. Both engines have recently been type tested and re-rated with 87 and 92 octane value fuels respectively. The English engine has a forged cylinder head with four valves and a maximum crankshaft speed of 2,500 revolutions per minute, a reduction gear to the propeller shaft of 2 to 1, and usually employs a two-blader wooden propeller. The American engine employs a cast head with two large hollow-headed sodium cooled valves, with a maximum crankshaft rotational speed of 2,050 revolutions per minute, and is produced as a direct drive engine, and

also with a gear ratio of 3 to 2, and employs a three-blader metal airscrew. It will be interesting to see how these two similar types of engine develop.

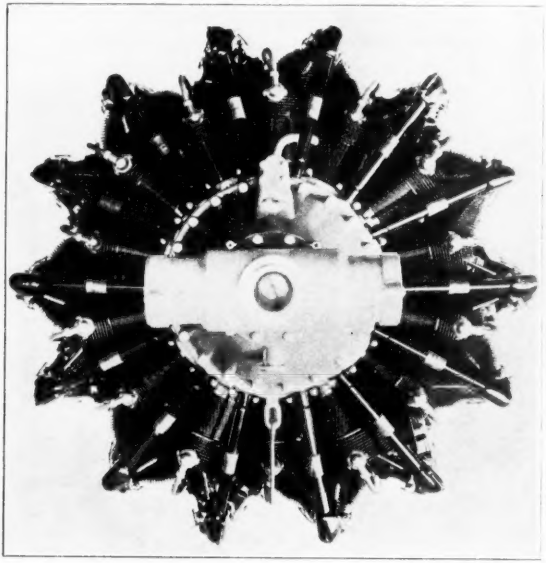
It is probable that, during the period under review, we shall see engines of this category developing 750 h.p. from 16 to 20 litres (976 to 1,220 cu. ins.) capacity, running at over 3,000 revolutions per minute, and with reduced weight and overall diameter, but I expect to see push rod valve mechanism replaced.

Category (c)—High-Power High-Efficiency Military type Engine

Under this heading I suggest that a suitably developed air-cooled engine may hold an important position in the future for military aircraft. In this category, however, keen competition must be expected from the liquid-cooled engine, which



The Gnome Rhone Mistral Major. *The Armstrong Siddeley Tiger.*



The Pratt and Whitney Twin Wasp.

FIG. 32.

Scale ratio of outside diameter: Mistral 100, *Tiger* 100, *Twin Wasp* 95.

can only be met by suitable layout and most careful detail design. I suggest that the wisest course is to endeavour to concentrate on the advantages of the direct air-cooled engine, and considerable care must be given to light weight, ease of mounting and installation, accessibility, and maintenance. High output per unit volume, and high crankshaft rotational speed must, I suggest, be faced in this category to meet competition.

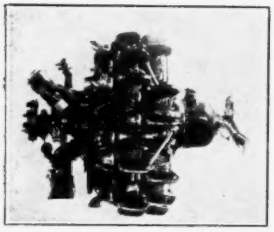
From experimental work the Bristol Company have been carrying out during the past two or three years, I am convinced that it is important to keep to a minimum the number of rows of cylinders for an air-cooled engine operating at high output and high crankshaft revolutions, and with a high rate of supercharge; and any attempts to draw comparisons from existing in-line light aeroplane engines may be erroneous.

Direct air-cooled cylinders require exactly the same weight of air to cool them efficiently whether disposed radially or in-line, and when in-line they must

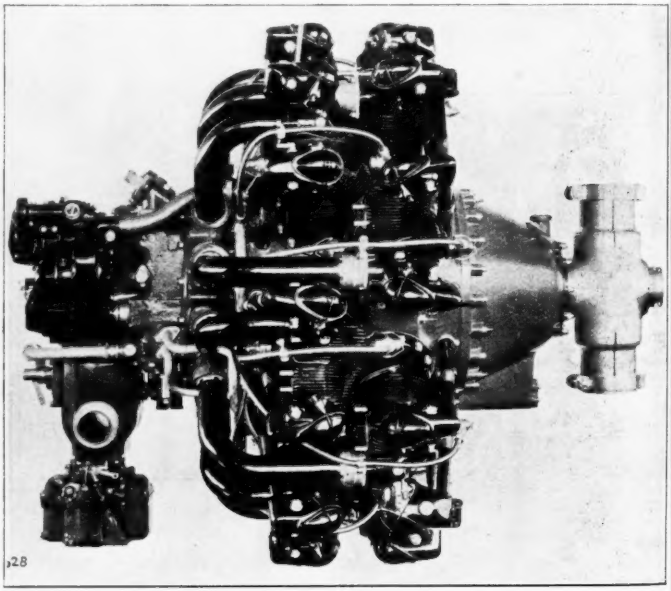
be suitably spaced and baffled, and are more prone to be upset by varying cooling conditions in different installations.

Research work by the Bristol Company has shown that it is extremely difficult to cool highly supercharged cylinders satisfactorily at full throttle for a sustained period, when more than three in a line, even when of comparatively small bore, at the low air speeds that must be faced in fully cowled installations.

Engines of this category will have to operate in heavily loaded machines with continuous high cruising output, and for the above reasons I do not favour the multi-bank in-line air-cooled engine for these powers, as it would appear that it must emphasise some of the problems of the in-line liquid-cooled engine, of equal swept volume, in an exaggerated form, in respect of simplicity, weight, length of crankshaft and crankcase, ease of installation, etc., while still having to meet at least as serious, and probably greater, cooling difficulties as on the radial type.



The Gnome Rhone Mistral Major.



The Pratt and Whitney Twin Wasp.

FIG. 33.

Scale ratio of outside diameter: Mistral 100, *Twin Wasp* 95.

I suggest that the most promising solution is the double row radial in compact form.

There is at present a strong school of thought both in Europe and America in favour of the 14-cylinder double row staggered radial engine for this category, and Fig. 32 shows a composite picture of the British Armstrong-Siddeley "Tiger" engine of 32.7 litres (1,994 cu. ins.) capacity, the French Gnome "K.14" engine of 38.6 litres (2,360 cu. ins.) capacity, and the Pratt and Whitney engine of 30 litres (1,830 cu. ins.) capacity, representative of the most advanced conceptions along these lines, and it will be interesting to watch the development

of these similar types. Fig. 33 shows side views of the Gnome " K.14 " and the Pratt and Whitney " Double Wasp " types. Although externally it would appear that all three engines present a strong family likeness, the American design differs considerably from the European types in several respects, the crankcase being built up of three forgings, with a central division wall, and it is of smaller swept volume, and would appear to have been laid out along the lines of high speed development.

I suggest that if the air-cooled engine protagonists are going to hold the field against the liquid-cooled engine in this category, where high efficiency will probably count more than in other types of aero engines, and light weight, compactness, and low specific fuel and oil consumption are of the utmost importance, neither the staggered radial, nor the multi-bank in-line air-cooled engine may be the ultimate solution. I suggest instead the double bank in-line engine as first seen in the design of the Curtiss " Chieftain " of some years ago. This layout lends itself to the use of both sleeve and overhead camshaft valve gear, one of which will be necessitated if a considerable increase of crankshaft rotation is to be satisfactorily employed, and it also enables a very stiff crankcase construction to be achieved.

During the period under review I suggest that there will be a call for an engine of this type of 850 to 950 h.p., which should develop its power from 20 to 25 litres (1,220 to 1,525 cu. ins.) capacity.

Category (f)—Large Flying Boat and Large Air Liner type Engine

Finally, with regard to the really large power plant for projected marine and civil aircraft, I am afraid that I have no slide from which to draw upon my fancy, but I suggest that, during the period under review, there will be a demand for a power unit of 1,000 h.p. to 1,200 h.p. which may be met by an air-cooled engine.

Owing to the size of the aircraft, scale effect will come into the layout, and cooling conditions may not, therefore, be so severe, but considerable attention must be paid to fuel consumption, and the engine must be capable of running for long periods without attention or maintenance.

If such an engine is required within the next five years, I think it must be of the four-cycle petrol type, but I would suggest that the most hopeful solution may be the compression ignition or Diesel engine of the two-cycle type, and of large swept volume of the order of 55 to 65 litres (3,355 to 3,965 cu. ins.) capacity, and capable of maintaining a continuous cruising horse-power of 800 to 900.

I am afraid these notes only provide a very precursory review of possible air-cooled aircraft engines for the future, but I hope they will provide some " food for thought."

I wish to thank the British Air Ministry, the Bristol Company, and other constructors, for their permission to make use of certain data and to exhibit slides of their products.

Discussion

Major G. P. Bulman (Member of Council, F.R.Ae.S.): Mr. Fedden was among the half-dozen leading men in the world, who by their creative force and driving power had carried the aero engine to its present stage of development. If evidence were wanted to support that claim they had it in the Paper. In formulating his speculations for the future, Mr. Fedden had recounted very modestly some of his own remarkable achievements of the past and the present. In doing so he had set out for the guidance of those who would read between the lines of his paper the fundamental principles on which all successful aero engine development must proceed. He thought the lecturer would agree that the faculty

of pure creative, inventive, genius really played but a small part in aero engine development. It applied in much the same way and in about the same proportion to the total make-up as two or three c.c. T.E.L. to a gallon of fuel; it was very effectively mixed but a confounded nuisance by itself, and not of much use. One of Mr. Fedden's greatest assets, and one of the fundamental principles, was his capacity to select and retain a competent and adequate staff and to supercharge them with some of his own extraordinary enthusiasm and energy and make them feel that it was only " the engine " that mattered. The speaker then gave instances of the individual efficiency of the Bristol Company's engineering staff. Secondly, Mr. Fedden allowed himself no room for complacency or self-satisfaction; he was always ready to meet the next demand of the Air Ministry and the aeroplane designer. And then he had an infinite capacity for concentration. Whether it was the development of an engine with an exhaust-driven blower, or a compression ignition or petrol injection engine, or a sleeve valve engine—in themselves problems entirely separate and distinct—he tackled them on the same form of engine, the same cylinder bore and almost invariably the same stroke. He limited the objective in each case. So many inventors, having got the idea of a new valve gear, or some particular component, set about the appalling task of designing and building a complete new engine around it, instead of applying their novelty, as far as possible, to some well-tried foundation. On the other hand, the Bristol Company organised such individual experiments to the furtherance of the whole engine design in current production. Indeed, he could best describe the system as a form of relay race, as compared with an individual long-distance marathon. He would not embark too deeply upon a discussion of the details of the paper. The underlying theme of the paper was to increase the horse-power obtained from a given capacity of engine. He would go further, and would apply that idea not only to the size of the engine as a whole, but to the individual cylinder. Mr. Fedden offered a useful corrective to the two schools of thought, one of which claimed that the compression ignition engine would entirely replace petrol, and the other, that it was of no use at all. There was yet a third school which suggested that heavy oil was of no use for military as opposed to civil use. As the lecturer had pointed out, the heavy oil engine had its limited, but important, use in both civil and military operation. Naturally, Mr. Fedden was an enthusiast for the single row radial engine, and he had wrung out of that basic design about as much as was likely to be got from it. In his paper he set for the future a goal of 40 h.p. per litre. Perhaps he had been a little unusually conservative. It was no secret that an output of that order was being obtained to-day, as was proved by several type tests and some hundreds of hours' flying—not with a radial engine but with an air-cooled in-line; at any rate there was in the paper a very striking claim for the air-cooled engine which those who were interested directly in liquid-cooled types could not afford to ignore, and while they would not be downhearted, they must appreciate that the way was long and they had, not a " pretty hot " pace-maker, but a very competent opponent whom it was going to take them all their time to beat. To that end they must push on and not relax their endeavours, and he doubted not that, as the result of the paper, there would be further intensive activity on the part of the liquid-cooled aero engine exponents—that they would accept the challenge and take up that air-cooled " Gauntlet " that had but recently been displayed.

Captain G. S. Wilkinson (Messrs. Napier's, Ltd.), F.R.Ae.S.: Mr. Fedden had not discussed the very important question of durability and increasing the length of life between overhauls. From the programme of development which he had indicated as likely to take place, it rather looked as if it would not be possible to increase the life between overhauls during that period, as the rate of progress of engine design would render engines obsolete so quickly that they would not become really reliable before they were out of date.

Captain Wilkinson was very much interested in the development of the sleeve valve. He congratulated the lecturer on the very valuable work that he had done in developing this type of engine, which the speaker thought had a very promising future.

Mr. Fedden had suggested in his paper that the type test for military engines should be made much more severe. It was Captain Wilkinson's opinion that for certain types of military aircraft the severity of the type test should be reduced, with a view to getting the highest performance from the engine with a life of about 100 hours between overhauls. For other types of military aircraft, and also for civil aircraft, a more durable engine would be wanted, and a severer type test than they had at present might be worth while for the second type of military engine.

In connection with lead bronze bearings, Mr. Fedden had suggested that it was necessary to have hardened shafts, in order to obtain satisfactory results. The speaker's experience with the Lion engine had been that the wear of the crankshaft with lead bronze bearings was no greater than the wear of the shaft with white metal bearings; in fact in all the type tests carried out on the Lion engine, the one which showed the least wear on the crank pins, the engine was fitted with lead bronze bearings.

Major F. M. GREEN, F.R.Ae.S.: An important point, to the speaker's mind, was the power taken to cool the cylinders. Mr. Fedden had made an exhaustive search through a number of engines to find which would give the best result. Major Green thought that he might have saved time if he had worked with a single cylinder and had measured the power required to cool it. This had been done recently with a modern cylinder of good design and it was found that, with the maximum temperature permissible, the amount of power to cool that cylinder was about 4 to 5 per cent. of the total power. It did not matter how the cylinders were arranged. If one had a cylinder of that design the best that could be done was to waste 4 or 5 per cent. of the horse-power. It mattered not whether the cylinders were radial or in-line, so long as air ducts were arranged which ensured cooling of the cylinders in a regular fashion and with the necessary velocity. If 5 per cent. were taken as a good all-round figure they had to provide that amount of cooling when the aeroplane was flying at the rather low speed for English aeroplanes of 90 miles an hour. As they expected a speed range of 90 to 180 miles an hour, that meant that the cooling at top speed was very much more than the cooling when climbing. With a power range of two to one, the power lost in cooling the engine went up to nearly 40 per cent. With a range of three to one it would be found that at the top speed they would be taking all the power to cool the engine. It was no use having this excess cooling at the top speed, it only wasted power. The only way by which they could make the air-cooled engine compete successfully with the water-cooled engine, when high speeds were required, was by devising some kind of variable cooling. The radiator was drawn into the body of the aeroplane, so that the amount of cooling available was constant, irrespective of the speed. He would like to know whether Mr. Fedden could give them any information of experiments that he had made with cowlings designed to vary the amount of cooling. That was the chief direction in which to improve air-cooled engines.

Major Green congratulated the lecturer on the figures supplied by the Bristol Company for the compression ignition engine. It was truly remarkable that, whereas in the petrol engine the power curve fell to $\frac{3}{4}$ at 7,500 feet, in the Diesel engine the compression ignition had not dropped to that figure at 15,000 feet. That suggested all sorts of possibilities in connection with civil aviation, particularly when the service was working from high aerodromes.

In conclusion, Major Green inquired whether Mr. Fedden considered that he could make an air-cooled compression ignition working on the two-cycle principle. That principle seemed to have the greatest possible chance of success,

and it would be interesting to know whether there was any possibility of air cooling on a reasonable expenditure of power.

Major KENNEDY, F.R.Ae.S.: He proposed to confine his remarks to one particular item, that of lubrication, and would ask the lecturer's permission to read a short paragraph which was omitted from his précis. Mr. Fedden had stated in his paper that since the introduction of the British Air Ministry of a straight mineral oil specification some three years ago, lubrication problems in England and America had been generally of a similar nature, except that he understood that higher viscosity oils were used on air-cooled engines in America than were permitted in England. A number of European countries still adhered to vegetable base oils for aero engines, chiefly, he believed, for national reasons, but he thought this practice was bound gradually to fall into disuse, due to ring gumming and corrosion problems and the instability of such oils over prolonged periods. A pronouncement of that kind from such an authority, said Major Kennedy, was valuable. Mr. Fedden then went on to look to the future when there would be an increase in the rate of revolutions and a general increase in the requirements of lubrication, and suggested that it would be necessary to go carefully into the question of reduction in oil consumption. Major Kennedy ventured to make a suggestion which he thought was worthy of consideration. It must be remembered that while they had at their disposal a straight mineral oil, that oil had a double duty to perform at present; it had to lubricate the crankshaft bearings and then had to deal with the much more difficult conditions in the cylinder. He thought it was generally known that the present mineral oils were compounded from two bases—an engine oil base and a cylinder oil base—and that the engine oil had a double duty to perform. In addition to lubricating the crankshaft bearings, it had to carry the cylinder oil up the walls of the cylinder. In that process it was subject to volatilisation, and that was very largely responsible for the consumption of oil. If the engine oil had only to deal with the bearings, its life would be very much lengthened.

In conclusion, Major Kennedy inquired if it were possible to consider whether those two functions could be separated so that they might have two different oil streams, each with its own special duty.

Major F. B. HALFORD: While the lecturer had confessed to a possible bias in favour of the radial engine, he wanted to declare straight away that his preference was for the in-line engine. Mr. Fedden had so thoroughly covered the whole of the problems facing the air-cooled engine designer that one could hardly think of any problem, other than that of detail design, that he had left out. If the speaker had any regret at all, it was that Mr. Fedden had not led them to the conclusion that was to be arrived at with regard to the type of engine air-cooled as dictated by minimum drag. Taking the time covered by the forecast, if aeroplane speeds were going up to 200-250 miles an hour, and presuming that wing engines continued to be used, was it not possible that the arrangement of the cylinders, particularly if the speed was to be doubled, might lead to a larger number of smaller cylinders being introduced, some of which might be rather difficult to tuck round a radial crank case? One of the biggest difficulties that one had to encounter when arguing the case for in-line engines came from the man who declared that trouble would always be experienced with the rear cylinders. On the contrary, it had been found consistently that those cylinders were the ones with which no trouble was experienced. He had listened with interest to the description of the cooling problem produced by ring cowling and the trouble that one had to get out of it. With that reduction of 25 per cent. in cooling air on the radial engine speed, the problem of the in-line engine did not appear to present any more difficulty.

Major Green had raised the question of controllable cowling. The cowling could be contracted at high speeds in order to obtain maximum performance, but if the engine were " non-contractable " in diameter, very little could be done to

reduce the drag. He thought that that fact should be put to the credit of the in-line engine. So far as weight and horse-power were concerned, Major Halford did not think it had been fully demonstrated what would be the saving in an engine of the radial type when they started to run it at the high speeds that he agreed would prevail in the future. The lecturer had referred to the six-cylinder in-line engine. For the first time Major Halford heard that on a French machine wing trouble existed. Perhaps Mr. Fedden would tell them whether it was a fuselage engine or a wing-mounted engine, because with his limited experience, up to the present there seemed to be no trace of any such trouble.

In conclusion, he added his meed of praise of the excellent paper that Mr. Fedden had given them.

Captain A. S. KEEP (Messrs. Westland Aircraft Company): A very good example of the modesty attributed to the lecturer by Major Bulman was to be found in his remarks on the compression ignition engine. They had had some opportunity of judging that in connection with the Phœnix engine—a very fine production of the Bristol Company. His (Captain Keep's) Company had had an opportunity of testing the engine out in aircraft, and had obtained extraordinarily good results. Mr. Fedden had casually mentioned that its running was comparable with that of the petrol engine. Their pilot reported that it was the smoothest-running engine that he had had, which was rather surprising because smoothness was not expected from a high compression engine like that. It was put into a machine formerly fitted with a Jupiter VIII.F. radial engine and was found to be much more smooth running than the latter. The starting-up was extraordinarily good, and so was the fuel consumption.

The real point was this: that they had always to consider what might be called the change-over point—that was to say, the length of cruising time for which the Diesel engine must run in order to make up for its extra weight—which was usually considered somewhere about six hours. With Mr. Fedden's engine it was found that cruising at about 10,000 feet the Diesel engine had more than justified its increased weight over that of the petrol engine in about four hours. That showed a very considerable advance on previous figures. That being so, they would probably hear more of compression ignition engines than had been indicated by some of the speakers that night—particularly when the engine was fitted with a supercharger.

Mr. HALL (Chief Engineer, Imperial Airways) congratulated Mr. Fedden on the fact that he had not only forged ahead from his own point of view, but was taking careful note of what his competitors all over the world were doing. That was evident from what he had told them that night about his recent visit to America, and he was to be congratulated on taking that broad view of the best way of keeping up the old country's head in aviation in all its branches.

Mr. Fedden had presented them with a picture of engines that were going to run indefinitely without overhauls; they were going to have no trouble. The speaker hoped that they were never going to cost anything or require fuel or oil. Of course, Mr. Fedden would readily understand that that was the way in which the greedy aeronautical engineer looked at these things! That was the sort of thing he was said to want, and he (Mr. Hall) believed it to be true. What they really required at the present time were engines which would give a better performance than the engines in use at the present day, because although those engines were excellent, the engineer required longer intervals between overhauls and even fewer troubles than were now experienced. The lecturer had indirectly promised them lower operating costs by supplying them with engines using fuel of higher octane value, which would more than offset the extra cost of such fuel. If he understood aright Major Kennedy's remarks on the question of lubrication, he (Major Kennedy) looked forward to the possibility of two methods of delivering oil into the engine, if not to two types of oil. The speaker had found by experience that one method of doing it was more than enough.

He did not think there was very much point in Major Kennedy's remarks about the volatilisation of the oil. His people knew of tests made with no appreciable result; the oil seemed just as heavy after the test as before. He wanted to see an oil with such a high viscosity that it could not even creep out of the engine, and would at the same time penetrate to every part of the engine, so that one need not be afraid of its suddenly drying up.

Turning to the question of the metal propeller, Mr. Hall declared that if it would do all that was claimed for it he would like to change over to-morrow, but he had yet to be convinced that the advantages to be derived from such action were real. The metal propeller started off with two bad disadvantages, first, the fantastically high first cost, particularly if it were of the variable-pitch type; secondly, the very great weight and consequent considerable drop in paying load. If those two difficulties could be overcome, the metal propeller might be an economical possibility. He would like to congratulate Mr. Fedden on the results obtained with the sleeve valve engine. For years he had held certain views on that subject which were known to Mr. Fedden, and it was only fair to say that, in his opinion, the latter had got much nearer to a really satisfactory, lasting, sleeve valve engine than anybody had yet done; in fact, Mr. Hall thought he had solved the problem and that in the course of a few years they might be using sleeve valve compression ignition engines.

Mr. H. B. Taylor: If Mr. Fedden's prediction as to the increased output of cylinders materialised, he anticipated something of a very drastic nature would have to be done with reference to the piston. It was a matter of history that the pistons formerly used in marine engines were very similar to those used in aviation engines to-day, namely, plain pistons which were uncooled directly. The large-engine manufacturer reached a stage where the size of his cylinder went up commensurate with the output. He had trouble, particularly in relation to the cracking of pistons, and was driven to take the step of internally-cooling the pistons.

Mr. Taylor suggested that Mr. Fedden might be driven to such a step. Such a design would add the required strength to the crown. It might be very difficult to employ efficiently sufficient fin area on the cylinder to take away the heat that the cylinder had to get rid of, and therefore impossible to cope with it on the cylinder alone. He suggested the line of development would be the internal cooling of pistons by direct circulation. Mr. Fedden had mentioned petrol injection. Did he refer to petrol injection into the induction pipe, or directly into the cylinder? He had not had an opportunity of reading the paper in detail, but to the best of his belief direct injection of petrol into the cylinder led to very great wastage; he also believed that the American engines operating on that system were not very economical. No doubt Mr. Fedden would be able to confirm or deny that. With reference to the climb curves of the compression ignition engine, he suggested that the improvement shown over the petrol engine was due to the fuel control being left in the same position throughout the climb, with resultant overheating and loss of fuel economy. If the cylinders would stand that degree of overheating, there was no reason why they should not stand it on the ground and why more fuel should not be pushed in at ground level—giving the engine a higher rating. To obtain a true comparison, the relation of fuel to air should be maintained the same throughout the climb as in the case of a petrol engine—by injecting less fuel. The Diesel engine would take in the same quantity of fuel if the control were left in the same place. Mr. Taylor suggested that that was the reason why the lecturer's two curves showed such a very different complexion.

Mr. F. R. Banks, F.R.Ae.S. (Ethyl Export Corporation) (*communicated*): Mr. Fedden mentions that it is not wise, at the present time, to exceed a lead concentration of 4 c.c.s per gallon, firstly, because of the poor lead consciousness of fuels with higher concentrations, and secondly, because engine problems are

considerably increased thereby. Turning to a later page, he found that Mr. Fedden is, if he might say so, somewhat contradictory, since he states, in effect, that engines have suffered, when using leaded fuels, if their specific powers were increased. He mentions that, even with fuels of low lead concentration, troubles occur if the cruising power is high in proportion to the maximum output.

His experience, in this country and in Europe, is that increasing lead concentration is not necessarily responsible for engine troubles developing, but these are much more prone to occur if the specific power is increased. He felt, however, that it is necessary to develop engines on fuels having reasonably high lead concentration, say 4 c.c.s per gallon, but if the valve gear is satisfactory with such a concentration it should remain so when a fuel containing about 7 c.c.s of lead per gallon is used.

Put in another way: If an engine gives trouble with a 4 c.c. concentration, it has not, in most cases, been possible to cure this or even reduce the magnitude of the trouble when using a fuel of the same octane value (made up with added aromatics) and containing only 1 c.c. of lead per gallon.

He was exceedingly interested in Mr. Fedden's sleeve valve development, and considers that he and the Bristol Company should be congratulated on a very fine effort. In this connection he would much appreciate the lecturer's views on the following: Does he think that the piston of a sleeve valve engine will be able to get rid of its heat adequately if and when engines are asked to cruise at, say, 190-200 lbs. per sq. in. b.m.e.p., as they certainly will do in about three to five years' time? Also, how will plugs behave under these conditions? He was well aware that more than 500 lbs. per sq. in. gross b.m.e.p. has been obtained from an experimental sleeve valve engine (Ricardo), but this is only for a very short period, and probably with low temperature boost.

The Americans have attained and even exceeded this figure with a poppet valve (sodium cooled) engine, running under similar conditions.

He reiterated that the single sleeve valve engine is well worth every bit of the money spent on its development, and he only raised these points as a matter of interest.

Lieut.-Colonel L. F. R. Fell, F.R.Ae.S. (Rolls-Royce, Limited) (*communicated*): Mr. Fedden expresses the opinion that neither liquid nor direct air-cooling will completely supplant the other for aircraft power plants; though, having read his paper very carefully, it is difficult to discern the duty which he considers can be more satisfactorily filled by a liquid-cooled engine than by an air-cooled. If one may, therefore, venture to criticise so excellent a contribution it is that the case for the air-cooled engine is somewhat overstated.

He entirely agreed with Mr. Fedden that the next ten years' progress in aero engine performance will be the result of steady development along present-day lines rather than by the introduction of any fresh principle. It is a fact that at no time in the history of aircraft engines over the last twenty years has there been less prospect of large improvement in engine performance than exists at the present time. During, and immediately after, the war period there were always in sight the advantages to be gained from supercharging, but supercharged engines have now been in general use for several years, and the increase in performance which the supercharger has made possible has already been experienced.

Mr. Fedden refers to the importance of ease of manufacture and the ability to speed up construction rapidly in time of emergency. While during the war period there is no question that the air-cooled engine of the day was a simpler proposition than the water-cooled, to-day there is no doubt that the position is reversed, and the air-cooled engine, with its large, complicated crankcase forgings and cylinder heads, requiring innumerable machining operations, presents a very much more formidable manufacturing problem in emergency than the present-day simplified water-cooled engine—following as it does along the lines of motor-car

engineering, and being therefore suitable for mass production in factories now devoted to pleasure car construction.

Mr. Fedden draws attention to the tendency to obtain increased aircraft performance by the use of engines of larger capacity. There seems little doubt that, at any rate so far as military aircraft are concerned, progress will proceed along these lines for several years to come, and that the time is not far distant when the 1,000 h.p. single-seater fighter will be a necessity. This will, of course, have the effect of increasing still further the size of the single-engined two-seater high performance bombing machine, and will, he suggested, provide a wide field for the use of the liquid-cooled engine, which, owing to its compact form and low drag, must continue to be supreme for these requirements.

He agreed with the remarks that any further startling reduction in weight is unlikely to be obtainable, and indeed at present ratings even so large a reduction as 10 per cent. would be only of very slight importance to the aircraft designer.

He very heartily agreed with Mr. Fedden's remarks on supercharging, especially where he refers to the prospects of further development of the exhaust-driven supercharger. The theoretical advantages of this form of drive are so great that a solution should be sought for the practical difficulties, especially at the present time in the light of improved knowledge of materials. The exhaust-driven supercharger is particularly applicable to the air-cooled radial engine, and indeed a fair measure of success was obtained from the exhaust-driven supercharger fitted by Mr. Fedden to a Jupiter many years ago. From the point of view of taking the altitude record, the exhaust-driven blower would seem certainly to be what is wanted.

Mr. Fedden is to be congratulated on the excellent series of experiments to which he refers that had been carried out on cylinder designs. The progress achieved certainly marks an important step forward for the air-cooled engine.

With regard to compression ignition engines, the remarks concerning Phœnix are particularly interesting, and he was very glad to know that a considerable measure of success has been achieved with supercharging so as to obtain a higher power for take-off, which, as stated by Mr. Fedden, has previously been the main drawback to the use of the compression ignition engine for aircraft work. He would be very interested to hear Mr. Fedden's views on the combination of the exhaust-driven supercharger and the compression ignition engine in this connection. The exhaust-driven turbine itself, owing to the lower exhaust temperatures of the compression ignition engine, should be a very much simpler metallurgical problem than was the case with petrol engines in the past, while at the same time the low fuel consumption, which is the main advantage of the compression ignition engine, would not be spoilt to the same extent as if the engine had to drive a mechanically-driven blower.

It is interesting to note that Mr. Fedden does not consider that direct petrol injection possesses much advantage, apart from the point that it permits of the use of hydrogenated fuels with high knock ratings which cannot be carburated owing to low volatility. Certainly the substitution of rather complicated moving parts, such as the fuel pump and injectors for the carburettor, will need important advantages to make it justifiable.

He must emphatically disagree with Mr. Fedden's conclusion in which he states that military engine design demands a more severe type test procedure than is at present in force. It has been proved by experience that the present complicated type test regulations ensure that engines will not pass into service which are incapable of completing between 400 and 500 hours between overhauls. So far as durability is concerned, this represents a very good standard, and the only effect, therefore, of stiffening-up the type test regulations will be that performances which might otherwise be made available to the aircraft will have to

be sacrificed so as to make the engine capable of withstanding stresses to which it is only submitted during its type test.

It is suggested that the double-bank air-cooled in-line engine possesses advantages as a form of construction for a large engine. He submitted that experience is all against this being the case, and experience in the air has always proved that the in-line air-cooled engine is extremely difficult to cool under flying conditions, which are never correctly reproduced on the test bench so far as cooling is concerned.

From the point of view of lightness and simplicity of construction, the radial engine in its various forms is still supreme, and, were it not for head resistance, still seems to be the ideal form of aircraft engine. As Mr. Fedden points out, new cowlings have greatly reduced the head resistance of the air-cooled radial, and he suggested it is better to put up with what resistance remains than to embark upon the enormous difficulties of obtaining equalised cooling between all the cylinders on the in-line engine.

Captain A. G. FORSYTH (Fairey Aviation Company) (*communicated*): There are one or two points in the lecture with which he did not agree, particularly under the " Advantages of using Direct Air-Cooled Engines for Aircraft Power Plants."

It is stated that the engine is simple to construct, of low cost, and easy to manufacture. In his opinion the present-day air-cooled engine is more complicated than the liquid-cooled type, and that the liquid-cooled type engine is easier to produce in quantities.

At the time of emergency it would be easier to produce large quantities of liquid-cooled engines, due to the comparatively simple castings used in the construction and also due to it being much easier to jig and tool for production. In the case of the air-cooled engine, as at present designed, in most cases the crankcases are manufactured from forgings and the crankcase is practically machined out of the solid.

There is difficulty in producing the forgings, due to the stamping machinery in the country being limited, whereas in the case of the liquid-cooled engine crankcases, which are usually made from castings, it would be quite a simple matter to duplicate the patterns and to have the castings manufactured all over the country.

The raw materials used in construction of liquid-cooled engines are easier to produce than those required for the air-cooled type.

Liquid-cooled engines are generally lighter than the air-cooled type, including the weight of the radiators and cooling medium, and the all-up weight of the completed aircraft is lower when the fuel consumption is taken into consideration for a given range. Further, the frontal area of the liquid-cooled engine and radiator is lower than that of the orthodox air-cooled type, and when surface radiators are used, the frontal area of the liquid-cooled type is practically half of that of the air-cooled engine.

There is little to be gained in the time of dismantling an air-cooled engine from an aircraft compared with the liquid-cooled type, as the connections of both types of engines are comparable. The question of dismantling an engine from an airframe solely depends upon the method of installation.

The question of ease of service and maintenance are about equal on both types.

In the case of the liquid-cooled engines, it is generally easier to replace components, and the cost of repairs and renewals is lower.

A point which is often emphasised in connection with the use of air-cooled engines is that it is possible to replace a cylinder. His general experience is that if a cylinder fails in service, it is necessary to dismantle the engine to ensure that no broken pieces remain inside, with the result that there is no saving to be gained in being able to detach a separate cylinder.

In regard to the development of air-cooled engines in the United States, the general progress which has been made in aircraft performance has been accomplished by careful aircraft design, which has consisted of cleaning up the structure and streamlining the aircraft fittings and incorporating retractable undercarriages.

In most cases, if liquid-cooled engines were installed, there would be a marked improvement in the speed of the aircraft and also an increase in the range.

He therefore considered that Mr. Fedden has over-rated the advantages of the air-cooled engine, and he felt that the liquid-cooled engine has much further to go than the air-cooled type, as the limitations in regard to increasing compression ratio and engine speed are not so limited as they are in the air-cooled engine.

Mr. ARTHUR NUTT (Vice-President, Wright Aeronautical Corporation) (*communicated*): He had read Mr. Fedden's paper on the above subject with a great deal of interest. This discussion is somewhat handicapped on account of not having available the various photographs and charts to which he refers throughout the paper. He would like, however, to make a few brief remarks on the various items which he has so very thoroughly discussed as a result of his vast experience on aero engines.

Section II.—Mr. Fedden refers to a comparison of the ease of servicing and maintaining liquid and air-cooled engines, indicating that the air-cooled engine is an easier engine to service and maintain. Contrary to this experience our 650 horse-power liquid-cooled engine appears to be easier to service and maintain than the nine-cylinder radial engines of 400 to 500 horse-power. The higher powered engines may require a little more maintenance, although with the present standards of design and reliability the larger engines should give about as good service as the smaller engines. Perhaps some of the difference in maintenance cost is due to the use of push rod valve gear rather than the overhead valve gear with full lubrication. The liquid-cooled Conqueror engine, for example, has a valve check each 100 hours and the engine is overhauled at 400-hour intervals. A number of these engines have had well over 3,000 hours in air line operation with few major changes; the original valves, connecting rods, crankshaft, cylinder blocks, etc., are still in use on these engines. Comparing the ease with which the engines may be overhauled, for example, the nine-cylinder radial with 12-cylinder hold-down nuts has a total of 108 nuts to remove to take off the cylinders, whereas a 12-cylinder engine of the same horse-power has only 40 cylinder hold-down nuts to be removed. In other words, the units in the liquid-cooled engine are larger and the engine, therefore, comes apart and goes together faster. Of course, an engine is not selected entirely on this particular feature, but I wish merely to point out the possible misunderstanding from the comparison.

This discussion is a result of watching both types of engines in manufacturing as well as service with the same organisations.

Section III.—Mr. Fedden's remarks about the ease with which weights are added in airplane structure are very much appreciated. Ten pounds additional weight on a 1,000-pound engine is considered a major offence; ten pounds added to the airplane receives far less consideration. In the U.S.A. sixty to seventy cruising horse-power is used on the fast transport ships which cruise 150 to 190 m.p.h., instead of 30 to 40 cruising horse-power as mentioned in the paper. These engines are delivering 17 to 20 horse-power per litre with 400 hours between overhaul and an estimated life of 3,500 hours.

Fuels.—Under the section of Fuels, Mr. Fedden discusses in considerable length the various octane ratings and the writer would appreciate information on the type of fuel test engine and the set of conditions which were used to obtain the figures quoted. In the U.S.A. the C.F.R. motor method is being used at the present time until such time as a better method is produced. The programme of the Aviation Gasoline Detonation Sub-Committee of the C.F.I. Committee

is investigating fuels in multi-cylinder aircraft engines in order to correlate the operation of these fuels in the multi- and single-cylinder test engines. It is hoped some time during 1934 to be able to publish the results of these tests which are expected to give some light on the ratings of aviation fuels. Some day the definition of an octane number may be discovered.

Supercharging.—This section is a very clear analysis and needs no comment.

Cooling.—In reference to engine cooling, it is evident that spark plugs are not keeping pace with the use of tetraethyl lead. It is hoped that something can be done to eliminate spark plug troubles which occur with full throttle operation at high b.m.e.p., particularly trouble with lead deposit.

They were in entire accord with Mr. Fedden's recommendations to eliminate all air starter connections in the combustion chamber. It may be necessary some time in the future to introduce a connection for fuel injection, but at least this spot in the cylinder will be somewhat cooled by the incoming fuel.

During the past year they had been having some of the experience through which the British have apparently passed, namely, the cooling of high-powered radial air-cooled engines fitted with reduction gears. As pointed out by Mr. Fedden the worst conditions are in a steep climb and it has been found necessary to establish a definite differential in pressure fore and aft of the engine by careful cowling to obtain good engine cooling.

Mr. Fedden's discussion of the type of fins used on cylinder barrels, we believe, should be tied up with the type of baffles which are used on air-cooled cylinders. The penetration of air in fins in the writer's opinion depends a great deal on the type of baffles used. In the U.S.A. it is becoming more and more the practice to use very close fitting baffles, particularly when the N.A.C.A. type of cowling is employed. The principle involved is that the air which does pass through the engine should be used for the purpose of cooling and only enough air for that purpose should be allowed to pass through the engine. The size of the slot in the cowl should be adjusted to the amount of air passing through the engine under which conditions the speed of the airplane is improved. With the short anti-drag ring probably more air through the engine will give better airplane speed, because there is less disturbance back of the engine under these conditions. There is a general tendency, however, towards the use of the longer cowl rings in the U.S.A. During the past year more careful study has been made of the air flow through engines. No doubt a considerable improvement can be obtained by the use of the proper type of cowling, both of the fixed and rotating type. We are in entire accord with Mr. Fedden's suggestion to standardise the complete equipment, including cowling, exhaust manifold, etc., but the airplane designers' co-operation is necessary if this goal is to be reached.

Increase in Speed of Rotation of Crankshaft.—The use of higher crankshaft speeds in aircraft engines is still an open question. For the past fifteen years we have been using speeds from 2,200 to 2,500 r.p.m. as normal at which all our type tests on these particular models are conducted. The possibility of going higher in engine speed has often been discussed with the inevitable result that the gain in horse-power is of doubtful value on account of the increased engine weight required and the necessity for more supercharging to obtain this added power at sea level which automatically reduces the altitude rating of the engine. The use of higher speeds, however, makes a smaller (but more expensive) engine which should have military and possibly commercial value. The smaller higher speed engine also runs smoother. There appears to be a definite tendency towards increase in rotational speeds, although the engines in this country which are in production at the present time are not being run in excess of 2,450 r.p.m. normal. As a matter of fact the model which our firm is selling in the largest quantity at the present time has a normal engine speed of 1,950 r.p.m.

Lubrication.—In the U.S.A. it is general practice to use 120 viscosity oil in aircraft engines, although where extremely hot weather is encountered 140 vis-

cosity oil is permitted. In very cold climates oils with a viscosity of 100 and even as low as 75 have been used. The universal application of very fine oil screens in the lubricating systems of aircraft engines by the firm with which the writer is connected has improved the appearance of bearing materials and checks Mr. Fedden's recommendations.

Compression Ignition.—Mr. Fedden's paragraphs on the compression ignition engines were very interesting and his " Phœnix " engine appears to be a very creditable endeavour. Very little has been done in the U.S.A. since the appearance of the Packard Diesel engine. This type of engine is very much in the background in the development programme in the U.S.A.

Direct Gasoline Injection.—While there may be no grounds for simplicity or cost of direct injection of fuel in the engine, I think the elimination of freezing is a very important factor. As the air lines gain more and more experience it is found that they are flying in weather which is much worse than they ever expected to experience. They fly in weather which has been reported to permit the formation of ice on the engine and on the intake air scoop of the carburettor. It appears that it may be necessary to provide heat over the entire air intake system of the carburettor. The elimination of the icing of the throttles, discharge nozzles and venturi in the carburettor will simplify the problem greatly.

Two-Stroke Engine.—He had a feeling that during the next five years rather than the next ten to fifteen years, there will be a definite tendency toward the two-stroke engine on account of the fact that both supercharger and fuel injection are reaching a stage of greater perfection. It appears that it may be necessary to use liquid cooling for these engines for some time to come, but with the knowledge being gained steadily on air-cooled engines it is not improbable that air cooling will be used eventually.

Sleeve Valve Mechanism.—After reading Mr. Fedden's article on this subject one wonders why he builds engines with poppet valves. He appears to have twelve good reasons for going to sleeve valve engines and the writer's reaction to this paragraph is that many designers of aircraft engines might well investigate this design.

Mr. Fedden's tabulation of the most useful types of aircraft power plants is very thorough and agrees very well with the analysis which has been made in this country. Mr. Fedden's paper is thorough and a very good analysis of the many problems encountered in the design, construction and operation of aircraft engines.

Reply to Discussion

Mr. Fedden, replying to the discussion, stated that he would like to couple the points raised by Major Bulman, with those of a similar nature made by Major Halford and Captain Wilkinson, in respect to the probable future horse-power output per litre. He, himself, had visualised a figure of 40 horse-power per litre for attainment during the period under review, chiefly because of the Air Ministry's, as he thought, wise regulation in regard to type tests and reliability. If Major Bulman was prepared to allow and encourage two types of engine, and two kinds of type test, then he thought we might go to a much higher output per litre.

As an illustration of this point, he had taken the trouble to tabulate the horse-power output per litre of a number of vehicles, such as motor cars, motor buses, and so forth, and he had been interested to find that the average output of the internal combustion engine, employed in the different classes of road transport, was something of the order of 21½ horse-power per litre. In spite of this comparatively low output, it is quite well-known that racing motor cars develop as much as 110 horse-power per litre, but this is only for a short life of a few hours. It might quite well be a logical conclusion for high performance military aircraft to have a highly efficient engine, with a shorter type test and a much shorter life.

Under such conditions, Mr. Fedden thought we might quite well expect 70 horse-power per litre, but he rather doubted if we should exceed 40-50 horse-power per litre, during the period under review, while the present type test conditions and engine life between overhauls were demanded.

As Captain Wilkinson had commented, he had not attempted to deal with the prolongation of life between overhauls in his paper. Quite frankly he would be satisfied if the present life between overhauls was retained, with the output increased to 40-50 horse-power per litre, and he felt that we should be kept pretty busy attaining this figure while the present standard of reliability and periods between overhaul were retained.

Mr. Fedden stated, however, that he wanted to feel that engines with a considerably longer life would be developed for large land planes and flying boats, where the engines would quite likely be tucked away high up above the ground or water, and constant routine maintenance would be impossible, and he hoped that these engines would be capable of running for 150 hours without any attention. Such an engine as this, must certainly have ample bearing surfaces and good maintenance qualities, and it was, in his opinion, quite a different proposition from the 40-50 horse-power per litre high efficiency Service type.

Dealing with the question of the hardened crankshaft, Mr. Fedden stated that possibly his opinion might have been somewhat biased by a rather unfortunate experience. An engine with soft shaft and lead bronze bearing, had successfully completed a hundred hours' type test, and had been re-built, and, after an hour or two's running, the engine had been wrecked, due to the seizure of the lead bronze bearing on the soft shaft, undoubtedly owing to foreign matter in the engine on the re-build. He agreed that quite possibly excellent results might be obtained by the provision of very thorough straining of the oil, but, after this unfortunate experience referred to, he was determined to insist upon hardened shafts in conjunction with lead bronze bearings.

Mr. Fedden stated that he was very glad that at last someone had carried out experiments as outlined by Major Green, and had actually ascertained the power required for cooling a cylinder. He noted that Major Green had found that it had been of the order of 4 to 5 per cent., and he thought this was a most interesting and instructive figure.

He entirely agreed with Major Green's remarks in regard to variable cooling. This, however, was one of those problems which was not wholly the engine man's job, as the question of installation came " into the picture," and it was rather difficult to get machines designed, with a suitably shaped body with which to try out such experiments.

Mr. Fedden stated that he had seen two machines in America with controllable cowling, and one installation being prepared for a fan-cooled engine.

Mr. Fedden stated that he favoured the two-stroke compression ignition air-cooled engine as being the only solution which could offer a power/weight ratio that, in any way, compared with the petrol engine. There was, undoubtedly, a good deal of development work to be done before the two-stroke compression ignition air-cooled engine was an accomplished fact, but, in view of the considerably lower cylinder temperatures that his firm had encountered on the four-cycle compression ignition type, he felt that the two-stroke had a chance, and it was within the bounds of possibility that such an engine would be realised during the next ten or twelve years.

Mr. Fedden stated that he was hardly in a position to make any comment on Major Kennedy's remarks on the two types of oil, and he felt rather dubious about setting out on an investigation of that sort, as he felt there were so many other more pressing problems.

No doubt many hours could be spent in discussing the points raised by Major Halford, namely, the problem of in-line air-cooled versus the radial air-cooled engine. He agreed that the in-line engine could be cooled, but at the expense

of complication, weight, and suitable baffling, all of which were serious matters. Granted that the in-line air-cooled engine could be cooled, it would always be longer than the liquid-cooled engine for a given swept volume, because of the necessary wider pitch of cylinders to allow for cooling, and it would thus have the disadvantages of the liquid-cooled engine, both as regards long crankshaft and heavy complicated crankcase, in a somewhat emphasised form.

Mr. Fedden agreed that the in-line engine is certainly of a lower drag form for certain types of aeroplane body, but he submitted that on machines of 600-700 h.p. or more, the cross sectional area of a modern military fuselage must be of such a size, to accommodate the equipment, that the radial type of engine can be quite suitably fitted in, leaving something to spare.

He appreciated Major Halford's point about controllable cowling on the small fuselage, but he was not at all sure that it applied to the larger type of machine.

With reference to Major Halford's last comment on the six-cylinder in-line engine, Mr. Fedden felt that Major Halford had misunderstood his remarks. The design of in-line air-cooled engine to which he had referred was one in which the crankcases of the engines were sunk into the leading edge of the wing of a twin-engined installation, the crankshafts being parallel to the leading edge of the wing, the cooling air impinging directly on to the cylinder heads, the cylinders lying end-on, in a horizontal plane. Wind tunnel tests had shown that this type of engine was bad from a drag point of view. It upset the air flow over the wing for a considerable portion of its effective length.

With regard to Mr. Hall's remarks on the question of lubricating oil, Mr. Fedden's opinion was that the oil technologists had got " to sit up and take notice " and provide a better oil, and, in his opinion, it was certainly time that they did something to keep pace with engine development.

Mr. Fedden stated that he was very much interested in Mr. Taylor's remarks about piston cooling. This was certainly a subject which was continually engaging the aircraft engine designers' attention, at any rate those who were trying to tackle engines with large bore cylinders. He stated that he was impressed with the seriousness with which this matter was being considered in America—he understood that it was thought absolutely necessary, with large size pistons, to introduce sodium cooling, or some form of cooling such as had been suggested by Mr. Taylor. He considered that, within three or four years, a satisfactory system of sodium cooling large-size pistons would have been evolved in America.

Referring to another question of Mr. Taylor's, namely, direct petrol injection, he understood that two methods of injection are being used in America—directly into the cylinder head, and, alternatively, into the induction pipe.

He agreed with Mr. Taylor that injection into the induction pipe was the most promising system as regards lowering fuel consumption.

Although at first sight there did not seem to be any remarkably strong argument in favour of petrol injection, at the same time it did give him " food for thought " after a talk he had had with the pilot of one of the dozen aircraft at present operating, day in and day out, on American air transport, employing direct petrol injection.

These pilots swear by direct petrol injection as regards regular and smooth running, and even make what would appear to be exaggerated statements about being able to take-off with a greater load on direct petrol injection. It must be admitted that these engines have been running successfully on direct petrol injection in America for some time, and the pilots have tremendous confidence in them. It is true that carburettor freezing is a serious problem in America, more so than in this country, but, bearing in mind the opinions on direct petrol injection engines on civil aircraft in America, and the work that has already been done on direct petrol injection in this country, he did not intend to give up the scheme without some further very careful thought.

Answers to Written Comments

Mr. Banks.—With reference to Mr. Banks' criticism of my comments in my paper on the subject of lead concentration and its effect upon engine durability, from the remarks contained in Mr. Banks' third paragraph, I do not think that he and I are really at variance on this subject. I stated that, for the time being, I thought it was not wise to exceed lead concentrations of 4 c.c.s per gallon for Air Ministry fuels. I should be happy to feel that Mr. Banks was correct in thinking that cylinders satisfactory with 4 c.c.s of lead would carry up to 7 c.c.s, and, undoubtedly, a great deal depends upon the design of cylinder and how much reserve it has against lead corrosion. We have carried out some satisfactory development tests with 7 c.c.s of lead on a type of cylinder which had satisfactorily passed all type tests on 4 c.c.s of lead, and, up to date, it has carried the higher concentration very well indeed. I think it is too early to say that such a cylinder would be wholly acceptable with 7 c.c.s of lead.

When discussing the effects of lead corrosion, I referred to some experiences I had been given in America, which were to the effect that, on the smaller size cylinders, at low cruising power of 12/14 horse-power per litre, 2-3 c.c.s of lead per gallon had been used with a fair measure of success some years ago. The large bore modern supercharged engine, when employing 20 horse-power per litre cruising, gave serious trouble to start with when using 2-3 c.c.s of lead per gallon, but this trouble was cured by suitable changes to cylinders and valve design to withstand lead corrosion.

With regard to Mr. Banks' question on the behaviour of the pistons of sleeve valve air-cooled engines, when cruising at 190/200 lbs./b.m.e.p., I hardly visualise this figure within three to five years' time, as he prophesies.

I do not think there will be any difficulty with air-cooled sleeve valve pistons, with a full throttle output of 200 lbs./b.m.e.p. and a cruising output of 140 to 150 lbs./b.m.e.p., within this period, but beyond these figures I should not like to go. I submit that the 500 lbs./b.m.e.p. obtained by Mr. Ricardo from a sleeve valve, and by Wright Field in America with a sodium-cooled poppet valve, are extremely interesting and valuable research work, but are not " practical politics " as regards a complete aero engine within the next five years.

Lieut.-Colonel Fell.—Replying to Lieut.-Colonel Fell's comments—in regard to paragraph (1)—I did state in my paper that I considered that neither the water-cooled nor the direct air-cooled engine would completely supplant the other during the period under review. I do suggest, however, that the air-cooled engine is likely to increase its field of usefulness, and the major portion of the paper is given up to suggested lines on which the different sizes of air-cooled engines could be most competitive.

I cannot agree with Colonel Fell's first paragraph, and much regret that he was not present to see the slide which showed the remarkably fine American light alloy drop-forged crankcases, reduction gear housings, and pistons. These American light alloy stampings are a remarkable piece of drop-forging technique. The walls are within .010 to .015 in. of drawing size. Bolt and tappet bosses, etc., are accurately formed within .002 to .003 in. These stampings require no profile machining, and are simply faced and bored, and are incomparably superior to the complicated castings of the in-line liquid-cooled engine for mass production. I have no hesitation in saying that the modern radial air-cooled engine is still a long way ahead of any other aero engine for emergency production.

With regard to paragraph (4) of Colonel Fell's comments, dealing with the remarks in my paper, I suggest that the power plant for the future high performance single-seater, and single-engined two-seater machines, will be governed by the total weight permissible for the engine, petrol and oil for a given period, and the bulk, or projected area, governed by the cross-sectional area of

the fuselage of a particular aeroplane. An engine fulfilling these conditions, and having as much horse-power squeezed into it as possible, will be the most suitable one, provided complication, reliability, etc., can be met, and, if the air-cooled engine can fulfil these demands, then I submit that it will be the most practicable solution. If there are certain specialised cases where it cannot meet these demands as suitably as the liquid-cooled engine, then I submit that the liquid-cooled engine will be the most satisfactory solution.

I am interested, and glad to note that Colonel Fell agrees, that we may hear more of the exhaust-driven supercharger in the future, and I feel that Colonel Fell's suggestion of a combination of exhaust-driven turbo-compressor, in conjunction with the compression ignition engine, may quite possibly prove the solution.

I note that Colonel Fell disagrees with my views about type test procedure, but I still feel that our type test conditions require stiffening up, and that a greater period of running at maximum r.p.m., to cover diving, bombing, and the introduction of v.p. propellers, is necessary.

I agree with Colonel Fell that the in-line air-cooled supercharged engine, in military sizes, is extremely difficult to cool, but I believe that the double-bank in-line air-cooled engine, with fairly small cylinders and running at high r.p.m., is the most promising solution for the low drag air-cooled power plant.

Captain Forsyth's remarks.—With reference to Captain Forsyth's criticisms of my list of advantages of the direct air-cooled engines from a manufacturing point of view, as set out in my paper.

Dealing with the various points raised in his comments:—

Para. 1.—I have no hesitation in saying that the production costs of direct air-cooled engines are lower than those of liquid-cooled engines of corresponding power. This I think can be definitely proved by reference to the retail price lists of representative English and American air-cooled and liquid-cooled engines. I think it will be found that, in every instance, the air-cooled engine is lower in first cost than the liquid-cooled engine, while, in addition, in assessing the total cost of the power plant, there is, in the case of the latter type, the serious items of radiators or steam condensers, piping, etc. I should estimate that the total cost of a representative English or American power plant, with its subsidiary equipment, is 20 to 25 per cent. lower in the case of the air-cooled, as compared with the liquid-cooled engine.

Para. 2.—Without any doubt, the direct air-cooled engine is easier to produce in large quantities, as the material required for its manufacture is more easily obtained in time of emergency. The production of complicated light alloy castings was a " key " point during the last war, and, from an examination of present-day liquid-cooled engines, I see no reason to think that this situation would be eased if the case of emergency arose again. I am sorry that Captain Forsyth was unable to see the slide I showed of the really excellent American light alloy drop forgings for air-cooled radial engine crankcase production. These stampings are beautifully made with main walls within .010 to .015in. and bolt and tappet bosses within .002 to .003in. of size, and requiring no further machining whatsoever beyond facing and boring. In my opinion the " key " to rapid production of the aero engine is the elimination of castings, no matter whether the engine is air-cooled or liquid-cooled, and an investigation into modern motor car production will show that every effort is being made to eliminate castings wherever possible. The fact that, at the present time, in this country, we have not adequate forging plant to make up-to-date drop forgings for direct air-cooled engine production is no argument against the suitability of air-cooled engines for large production if and when required. This country must instal modern up-to-date forging plant, if it is ever going to keep in the forefront of engineering, and this is a condition that I am happy to say I believe will be remedied within the next year or two, and, when it is remedied, that engine

which uses drop forgings in place of castings will score from a production point of view to a very large extent.

Para. 3.—I am quite convinced that raw materials for radial engines are much easier and more rapidly produced, in large quantities, than the in-line engine.

Para. 4.—I do not agree that liquid-cooled engines are generally lighter than the air-cooled type, including the weight of the radiators and cooling medium. Published figures show that for powers of 500-600 h.p. the advantage lies with the air-cooled engine to the extent of about 200lbs.

It is agreed that the frontal area of the liquid-cooled type, with surface radiators, is considerably lower than the corresponding air-cooled installation. Experiments have proved, however, that this form of liquid-cooled installation is impossible for Service aircraft, and only suitable for special racing machines where the utmost care is maintained.

Steam cooling, in conjunction with leading edge condensers, is certainly extremely attractive from a low drag point of view. In my opinion, there are many problems to solve, and weight and vulnerability are conditions, the seriousness of which only Service experience can determine. In the meantime, it must not be considered that direct air-cooled engine development will stand still, and it is quite possible that the direct air-cooled engine protagonists may have some effective counter to offer to steam cooling.

Para. 5.—I agree that the rapid dismantling of any engine from an airframe is an important problem, but I am of the opinion that the radial engine can always be mounted, so that it is considerably easier and more rapidly dismantled than an in-line liquid or air-cooled engine.

Para. 6.—The existing figures of the best established Civil Air Transport Companies, throughout Europe and America, show that the maintenance cost of air-cooled engines is about 40 per cent. less than the liquid-cooled engines.

Para. 7.—Similar figures to those stated in para. 6 show that the cost of repairs and renewals on air-cooled engines are lower than on liquid-cooled engines.

On general principles, I agree with Captain Forsyth that the best and most economical way of servicing aeroplane engines is to take out the unit completely for an inspection and overhaul. At the present time, however, both in military and civil aircraft, it is general practice to top overhaul the engine. This procedure is perfectly feasible and practicable in the case of the air-cooled engine, but almost impracticable in the case of the in-line monobloc liquid-cooled engine.

I do not agree with Captain Forsyth's remarks in regard to the reasons for the almost universal use of the air-cooled radial engine in America. Certainly progress has been made in American machines by careful aircraft design, with correct shape of fuselage, and the incorporation of retractable undercarriages, but it must not be thought that good and reliable liquid-cooled engines do not exist in America, and have not been tried out against the corresponding air-cooled installations. In certain recent American competitions, liquid-cooled engines have been tried out against air-cooled installations, and the former have had the advantages enumerated by Captain Forsyth, but have not necessarily " gained the laurels " for the aircraft into which they have been installed.

Mr. Arthur Nutt.—In reply to Mr. Arthur Nutt's written comments:—

Para. 1 dealing with Section II—ease of servicing and maintaining liquid and air-cooled engines.

I note with interest Mr. Nutt's remarks in regard to the comparable servicing of liquid and air-cooled engines, both being produced by his one organisation. I feel that a great deal depends upon the detail exigencies of the design, but I cannot but feel that Mr. Nutt will agree with me, on general principles, that the radial air-cooled engine must be more easy and more simple to dismantle from an airframe and overhaul, than an in-line engine. In any case I have read many written comments in the American aviation Press to this effect, and, if the argu-

ment did not hold good, I cannot but think that some of the very efficient and modern high speed American civil aircraft would be using " Conqueror " engines.

A comparison in regard to valve mechanism is, I suggest, a point in favour of the four-valve as against the two-valve, although I agree that it is desirable to eliminate any type of push rod gear if possible from an aero engine.

Fuels.—Octane numbers for Air Ministry Specifications No. 224 (77 octane) and No. 230 (87 octane) are determined as follows:—

> " The anti-detonation value shall be not less than 77 or 87 octane number respectively, when determined by the standard ' C.F.R. Motor Method ' modified so that the unit is run with a mixture temperature of 260°F."

This method of determining the conditions for arriving at the octane number was laid down by the Institution of Petroleum Technologists as the result of a series of tests on reference fuels, carried out by the R.A.E., Rolls-Royce, and the Bristol Company, during 1933, the results of which were incorporated in a publication by Mr. Pye in July, 1933.

I was much interested in the programme of tests laid down by the Aviation Gasoline Detonation Sub-Committee of the C.F.R. Committee, which was explained by Mr. Nutt at the Chicago Conference last September. I consider this programme of tests a most valuable one, and shall wait the publishing of the results with great interest.

Cooling.—I am very interested in the remarks by Mr. Nutt under this section, and feel that in America a more practical solution of the cooling of direct air-cooled engines has been made than in this country, and I am hoping, in the near future, to see some installations in this country incorporating the views set out by Mr. Nutt.

Increase of Speed of Rotation of Crankshaft.—While having the highest opinion of the technique and general design of American aero engines, may I submit that the real answer to Mr. Nutt's comments under this heading, is the fact that American air-cooled engines have only two valves per cylinder, and that, at the present time, this must be a problem which is causing the designer some thought. From a careful, and, I hope, unbiassed study of the large single bank air-cooled radial of English and American origin, I am of the opinion that there are many advantages in the higher operational speed, and, although four valves per cylinder make a somewhat heavier, and more complicated and expensive layout, $5\frac{3}{4}$in. bore cylinders can be operated quite satisfactorily up to 2,700 r.p.m. with a very great advantage from the smooth running point of view, and without any propeller problems whatsoever.

Two-Stroke Engine.—I am very interested in Mr. Nutt's remarks in regard to the two-stroke engine, and shall await results with anticipation. It would appear to me that the two-stroke compression ignition engine is a possible solution for direct cooling, but, without some very revolutionary changes in material and general technique, I feel it is hopeless for the petrol engine.

ABSTRACTS AND NOTICES

FROM THE

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(Prepared by R.T.P.)

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PART I.—PHYSICS AND ENGINEERING SCIENCE

Aircraft Design, Etc.

Tour of the Dornier Do.X, 1930-32. (Fr. Christiansen, Z.V.D.I., Vol. 77, No. 21, 27/5/33, pp. 561-564.) (5.10/27001 Germany.)

A brief analysis is given of the various sections of the flight, with a forecast of long distance flying developments.

Researches on the Effect of Wing Fuselage Interference in a Low-Wing Monoplane—N.A.C.A. Tech. Note No. 460. (M. J. Hood and J. A. White, Airc. Eng., Vol. 5, No. 55, Sept., 1933, pp. 203-206.) (5.11/27002 Great Britain.)

The sensitive flow over the upper surface of a wing is liable to serious disturbance by the body and struts, which may produce or accentuate tail vibrations, especially near stalling incidence.

Fillets smoothing off the sharp corner between body and wing had a beneficial effect and reduced the maximum amplitude of the vibration to one-seventh. A combination of fillet and N.A.C.A. engine cowling, by directing the wake over the wing, increased the maximum lift 11 per cent. and reduced the minimum drag 19 per cent., while reducing the amplitude to one-quarter.

Photographs and sketches show the dimensions and set up of the experiments, both model and full scale, and specify the filleting of the sharp corner.

Lift drag curves exhibit the experimental results. There are anomalies which obscure the general view of the phenomenon.

Heating and Ventilation of Aeroplane Cabins. (M. Gould Beard, Aeron. Eng., Vol. 5, No. 2, April-June, 1933, pp. 53-60.) (5.14/27003 U.S.A.)

Wide extremes of temperature in a continental climate, cooling in summer and heating in winter, air temperatures of 90°F. in summer and −20°F. in winter (−40°F. in Canada) may be expected.

For cooling, good ventilation plus altitude are usually sufficient. Townend rings bring a layer of hot air over the nose of the aeroplane.

Aerofoil Characteristics as Affected by Protuberances of Short Span. (E. N. Jacobs and A. Sherman, N.A.C.A. Report No. 449, 1933.) (5.20/27004 U.S.A.)

In continuation of Report No. 446 (see Abstract 27005) experiments were carried out with faired protuberances extending only a small fraction of the span. The most sensitive position is at mid-span, where the decrease of lift is greatest.

Methods of aerofoil theory are used to generalise the results as a function of span lengths of protuberances. Distributions of lift are exhibited graphically and show a marked drop around the protuberance.

Four references.

Aerofoil Characteristics as Affected by Protuberances. (E. N. Jacobs, N.A.C.A. Report No. 446, 1932.) (5.20/27005 U.S.A.)

Protuberances were attached to the upper surface at four selected stations. The first type of protuberance consisted of a strip of sheet metal protruding at right angles from the aerofoil surface and may be regarded as a " spoiler." The second type was formed by adding fairing to the grid type and may be regarded as making the best of an essential external fitting, running the whole span length by fairing it. Extensive experimental data are given graphically in 48 charts in a form suitable for designers.

Five references.

New Resistance Measurements by the Momentum Method. (M. Holtermann, Z.F.M., Vol. 24, No. 6, 28/3/33, pp. 157-163.) (5.20/27006 Germany.)

The results obtained on wing profiles by the impulse method are in reasonable agreement with wind channel results obtained by direct weighing. In full-scale measurements the flow was too unsteady for comparison of results.

Theory of Arbitrary Wing Sections. (T. Theodorsen and I. E. Garrick, N.A.C.A. Report No. 452, 1933.) (5.20/27007 U.S.A.)

The Joukowsky transformation is generalised by the introduction of Fourier expansion, and a number of elegant transformations of the analytical expression are given. The numerical solution proceeds by successive numerical approximations which converge with great rapidity for usual types of aerofoil, and for a wide range of other contours.

The successive steps in the transformation, from a square to a circle, are shown graphically. Tables are given to facilitate computation, and numerous contours and pressure distributions are shown graphically.

Nine references.

Relation between Incidence of a Wing Profile and Velocity and Pressure Fields. (F. Weinig, Werft-Reederei-Hafen, Vol. 14, No. 10, 15/5/32, pp. 127-131.) (5.20/27008 Germany.)

The elements of the circulation theory of lifts and transformation from a circle to a wing profile along with the corresponding velocity potential fields, are discussed and comparisons are made with experiments.

The Wing of Least Induced Resistance. (E. Prandtl, Z.F.M., Vol. 24, No. 11, 6/6/33, pp. 305-306.) (5.20/27009 Germany.)

The so-called elliptic distribution of lift gives the minimum induced drag for a given total wing lift, but this is a purely aerodynamical result and does not give the " best " distribution under consideration of structural weight and resistance.

The more general problem is intractable, but an intermediate problem is here stated and solved. The weight of the wing spars is taken into account and modifies the best shape and distribution of lift. The weight per unit length of the spar is taken as proportional to the bending moment at each point of the spar, to a useful approximation. The integral of the moment along the spar is then proportional to the total spar weight and is transformed, in a simple manner, into the 2nd moment of the lift along the spar. The modified problem of best lift distribution is found to be satisfied by the introduction of a quadratic factor and is solved formally. Numerical values are tabulated and shown graphically. The corresponding wing plan, for uniform incidence, is trapezoidal.

One reference.

Flow Round a Wing Profile with Applications to Hydraulic Machines. (F. Seewald, Z.V.D.I., Vol. 77, No. 21, 27/5/33, pp. 573-580.) (5.20/27010 Germany.)

A summary is given of the fundamental results of the circulation theory of reaction, with a cursory note on applications to compressors.

Thirty-nine references.

Trapezoidal Wings with Variable Incidence. (J. Hueber, Z.F.M., Vol. 24, No. 11, 6/6/33, pp. 307-310.) (5.20/27011 Germany.)

The methods of Prandtl's paper (see Abstract 27009) are extended to trapezoidal wings of variable incidence.

Examples of distribution of lift, incidence, circulation, induced resistance and induced downward velocity are shown graphically for various combinations of taper and incidence, taken from sailing aeroplanes.

Ten references.

Aerodynamical Properties of Biplane Wings of Trapezoidal Plan. (J. Hueber, Z.F.M., Vol. 24, No. 9, 13/5/33, pp. 249-251, and No. 10, 29/5/33, pp. 269-272.) (5.20/27012 Germany.)

Analytical methods are developed for calculating the circulation and effective incidence from the geometrical incidence and chord length. Developments are assumed in Fourier series and the coefficient determined by standard methods. Certain analytical irregularities, with a sharply cut-off wing tip are avoided by assuming a slight rounding off.

The calculated distributions of circulation lift, effective incidence, induced incidence and induced resistance are shown graphically for six degrees of taper and three aspect ratios. Derived relations and comparative values are also shown. The corresponding formulæ are given, but no numerical work is reproduced.

Ten references.

Drag of Streamline Bodies as Affected by Protuberance. (I. H. Abbott, N.A.C.A. Report No. 451, 1932.) (5.30/27013 U.S.A.)

The methods applied to wing profiles in Reports 446 and 449 are here applied to two model airship hulls. Streamline protuberances produced little adverse effect, especially on higher Reynolds numbers. Groups of six and eight tail fins produced an increase in drag of 8 per cent. and 11 per cent. respectively, and the cars an additional 10 per cent. of the fair hull drag.

Anomalies were found in reducing the measurements which are partly accounted for by mutual interference between car and hull.

Six references.

Aircraft—Landing Gear

Elastic Characteristics of Aeroplane Carriages. (R. Verduzio, L'Aerotecnica, Vol. 13, No. 3, March, 1933, pp. 163-177.) (5.50/27014 Italy.)

Expressions are formed for the work to be absorbed in landing and for the required elastic and damping forces in the undercarriage. Two diagrams of landing acceleration are reproduced, one for landing in stalled attitude with accelerations running up to 2.78, the other for a landing in normal flying attitude with initial landing acceleration exceeding 5g.

Parameters are introduced to simplify the equations, and their values are shown graphically for a range of conditions likely to occur in practice.

See Abstracts 27082 and 27083.

Hydrodynamics of Marine Aircraft. (J. H. Lower, J.R. Aer. Soc., Vol. 37, No. 269, May, 1933, pp. 423-434.) (5.51/27015 Great Britain.)

A concise account is given of test methods for determining hydrodynamic stresses on floats and hull, and resultant lift and drag. Observed stress distributions are shown graphically and applications to design are considered.

Photographs of large flying boats are reproduced.

Testing of Mechanical Brakes. (K. Kutzbach, Z.V.D.I., Vol. 77, No. 17, 29/4/33, pp. 443-447.) (5.58/27016 Germany.)

The unavoidable heating of brakes requires consideration as a fundamental factor in design, and the investigations here discussed enable the temperature rise to be predetermined with reasonable accuracy. The application of asbestos to protect the brake shoe allows a rise of temperature to as much as 400°C. without destructive action.

Numerical results are shown graphically in seven diagrams. A sketch of the test apparatus is given.

Four references.

Airscrews

Measurements of Free Running Screws in the Cavitation Tank of the Hamburg Shipbuilding Research Laboratory. (H. Lerbs, Werft-Reederei-Hafen, Vol. 14, No. 12, 15/6/33, pp. 169-172.) (5.60/27017 Germany.)

From the principles of dynamical similitude, rules for transformation from model to full scale are obtained and applied to expressions which are developed for the centrifugal reduction of pressure at the axis and illustrated graphically. The test installation is described with photograph and sectioned sketch. Velocity correction factors for different disc areas are calculated and plotted and a numerical example is worked out.

Seven references.

Investigation on Propeller Profiles, with Reduced Sensitivity to Cavitation. (H. Holl, F.G.I., Vol. 3, No. 3, May-June, 1932, pp. 109-116.) (5.60/27018 Germany.)

The experiments were carried out in a wind channel on a series of wing profiles with flat pressure side and suction side composed of one or more circular arcs. The symmetrical profiles with the greater thickness at mid-chord gave the smallest pressure range and were thus least subjected to cavitation. The results are stated to be in satisfactory agreement with theory.

Cycloidal Propelling Blades. (E. Schneider, Werft-Reederei-Hafen, Vol. 14, No. 12, 15/6/33, pp. 161-169.) (5.643/27019 Germany.)

An elaborate graphical vector diagram analysis is carried out of the reactions on impeller blades moving in helicoidal oscillating and cylindrical paths.

The method is analogous to that employed in turbine blade design, and no reference is made to modern theory of wing reactions.

Airscrew Design. (D. L. H. Williams, J.R. Aer. Soc., Vol. 37, No. 270, June, 1933, pp. 479-508.) (5.050/27020 Great Britain.)

The principles underlying the design of a successful aeroplane-engine-airscrew combination are reviewed. The paper is comprehensive but is in general qualitative, though illustrated by sufficient representative figures and data to give standards of present-day practice. Due importance is assigned to the development of aerodynamical theory on the one hand, and to systematic measurement on the other.

A number of specialists took part in the discussion which followed. Paper and discussion present the subject in sound perspective.

Airscrew Vibrations. (M. Hansen and G. Mesmer, Z.F.M., Vol. 24, No. 11, 6/6/33, pp. 298-304.) (5.060/27021 Germany.)

The work of British investigators published in Reports and Memoranda, and covering the period 1917-1926, is reviewed. A new analytical method of calculating vibration frequency is developed and checked by means of model experiments. There exists danger of resonance between natural harmonics of bending and firing impulses of the engine. The maximum stresses occur at approximately .7 to .8R., and in wooden propellers are marked by cracking of the varnish. In metal propellers resonance leads to fracture near the blade tips.

Instruments

Influence of Air Temperature and Pressure on Pressure Head Readings. (H. G. Kiel, Z.F.M., Vol. 24, No. 10, 20/5/33, pp. 281-284, D.V.L. Report 319.) (6.23/27022 Germany.)

Four types of Venturi pressure heads were calibrated and the coefficients, $\overline{K}$ = pressure/suction, are shown as functions of Reynolds number R. An expression is formed showing the effect of pressure and temperature as an arbitrary function, and values of this function, as determined by experiment, are shown graphically. In unfavourable cases the error may be as great as −8 per cent., and in ordinary cases −5 per cent., an amount which certainly requires correction in accurate determinations of aeroplane speed.

Thirty references.

Principles of Hot Wire Instrument for Measurements of the Velocity Vector. (J. Ulsamer, F.G.I., Vol. 4, No. 3, May-June, 1933, pp. 121-128.) (6.40/27023 Germany.)

The elementary principles of heat conduction and electrical resistances are summarised, with their application in the three component hot wire instrument. Calibration is discussed and calibration curves are reproduced. Non-dimensional parameters are used freely in semi-empirical formulæ, and the results are generalised on the principle of dynamical similitude.

Seventeen references.

The D.V.L. Torsional Vibration Apparatus. (A. Stieglitz and E. Gilbert, Z.F.M., Vol. 24, No. 9, 13/5/33, pp. 253-255, D.V.L. Report 318.) (6.48/27024 Germany.)

A technical description is given of the installation, with two photographs and four sketches. A 5 k.w. D.C. motor drives the installation under test up to 10,000 r.p.m.

The installation is suitable for testing damping devices and for fatigue tests of materials. All the necessary data are recorded simultaneously, with sufficient accuracy.

Oscillographs for Ten Thousand Cycles per Second. (A. M. Curtis, Bell Tele. B.711, 1933.) (6.48/27025 U.S.A.)

The vibrator is strung to a natural frequency of 4,500 herz. and equalised up to from 10,000 to 12,000 herz. by electrical circuits. The description of the apparatus is illustrated by photographs and a perspective sketch of the whole assembly and of details. Characteristic curves show frequency as functions of resistance and of deflection under different settings. Three oscillograms are reproduced.

Six references.

A Simple Method for Making Photographic Records of Motion. (E. Raetsch, Z. Instrum., Vol. 53, No. 6, June, 1933, pp. 283-285.) (6.48/27026 Germany.)

Small vibrations in space or large vibrations in a plane are recorded by fixing one or more transparent screens to the object to be investigated. These screens are provided with a series of reference lines and points which are photographed on a rotating drive through a narrow slit. Numerical values of the displacements are obtained from the dimensions of the optical system and a separate calibration is unnecessary.

Gyro Compass and Ship Manœuvres. (J. W. Geckeler, Ingenieur Archiv, Vol. 4, No. 2, April, 1933, pp. 127-152.) (6.503/27027 Germany.)

In a previous communication (Ing. Archiv. Band 4, No. 1, 1933, p. 66) the general theory of the gyro compass was developed and the formal solution without damping was given. The present note considers the effect of damping.

For the use of artillery at sea, a steady compass reading (varying by not more than three minutes of arc per minute of time) is of greater importance than a true absolute reading. This seems to indicate that the amount of damping should be controllable.

A New Askania Pendulum Sextant. (H. Fuss, Z. Instrum., No. 4, April, 1933, pp. 152-159.) (6.532/27028 Germany.)

An air navigation sextant, constructed by Zeiss, employs a pendulum instead of the more usual bubble. The pendulum deflection is observed direct in the eye-piece, so that a number of observations can be taken in quick succession. The suspension and damping of the pendulum have been carefully studied.

An accuracy of $\pm 3'$ is claimed, giving a fix within about three miles.

Aircraft Sextant for Visible Horizon. (L. Becker, J.R. Aer. Soc., Vol. 37, No. 272, August, 1933, pp. 703-707.) (6.532/27029 Great Britain.)

Three short arcs on the visible horizon are brought into the field of view and appear as straight lines cutting at about 60°. When the centre of the field is brought to equi-distance from these three lines the best compromise is obtained. The error appears only in 2nd order terms, hence an error of $\frac{1}{2}°$ in observation squared gives an error from the horizontal of the order of one minute.

The elementary spherical trigonometry is worked out.

Measurement of Fundamental Sound Generated by an Airscrew in Flight. (E. T. Paris, Phil. Mag., Vol. 16, No. 103, July, 1933, pp. 50-61.) (6.95/27030 Great Britain.)

The sound was recorded by a resonant hot wire microphone calibrated against a Rayleigh disc and tuned to the fundamental note of the airscrew, which is taken to be the number of airscrew blades multiplied by the revolutions per second in accordance with experiment. A diagram of connections shows the electrical layout. The frequency was recorded simultaneously.

Numerical results are given in a table. The sound energy output was computed as 55 watts, in comparison with the figure of 29 watts given by Kemp for a two-bladed screw developing 500 h.p. at 1,850 r.p.m.

Eleven references.

Aircraft Flight

Path of Minimum Flight Time between Two Points. (P. Frank, Z.A.M.M., Vol. 13, No. 2, April, 1933, pp. 88-91.) (7.15/27031 Germany.)

The problem of the path of minimum flight time is analogous to the optical path of a ray in media of variable refractive index. A formal treatment in vector notation leads to the expected analogous result.

Six references.

Lateral Control near Stalling. (N.A.C.A. Reports and Technical Notes.) (7.25/27032 U.S.A.)

A research programme has been carried out under the following list of Reports and Technical Notes.

N.A.C.A. Reports.

419 Ordinary ailerons on rectangular wings. F. E. Weick and C. J. Wenzinger.
422 Slotted ailerons and frise ailerons. F. E. Weick and R. W. Noyes.
423 Ordinary ailerons rigged up 10° when neutral. F. E. Weick and C. J. Wenzinger.
424 Floating tip ailerons on rectangular wings. F. E. Weick and T. A. Harris.
439 Spoilers and ailerons on rectangular wings. F. E. Weick and J. A. Shortal.
444 Skewed ailerons on rectangular wings. F. E. Weick and T. A. Harris.

N.A.C.A. Technical Notes.

443 Handley Page tip and full span slots with ailerons and spoilers. F. E. Weick and C. J. Wenzinger.
445 Straight and skewed ailerons on wings with rounded tips. F. E. Weick and J. A. Shortal.
449 Tapered wings with ordinary ailerons. F. E. Weick and C. J. Wenzinger.
451 Various control devices on wing, with fixed auxiliary airfoil. F. E. Weick and R. W. Noyes.
458 Various floating tip ailerons on rectangular and tapered wings. F. E. Weick and T. A. Harris.

The details of the model apparatus are given by dimensioned sketches and tabulated numerical data. The results were obtained under specified wind channel conditions, the lift, drag, yawing and rolling moments being measured for systematic variation of the control settings.

A great mass of test figures is recorded in numerical tables and drawn graphically in diagrams of curves. Conclusions are drawn as to the comparative effectiveness of each device. Designers will find it advisable to study at first hand this body of experimental data which is not suitable for abstracting in detail.

Wings with Variable Curvatures and Slot Openings. (J. Lacaine, L'Aéron., No. 168, May, 1933 (Supplement), pp. 41-44.) (7.72/27033 France.)

The details of the variable wing are shown in sketches and in a photograph. Experimental polar curves of lift and drag are reproduced and show the increase

in lift and drag at three different settings. The results are in general agreement with previous work.

Three references.

Engines—Thermodynamics

Combustion Processes in Aircraft Engines. (H. K. Cummings, Aeron. Eng., Vol. 5, No. 2, April-June, 1933, pp. 65-73.) (8.13/27034 U.S.A.)

A brief historical account is given of the development of research methods, illustrated with graphical characteristics, a photograph of flame propagation and photographs of comparative flame front spectra.

The complete analysis of the phenomena remains obscure, and recommendations for further research by an influential U.S.A. committee are reproduced.

Thirty-four references.

Pressure Increase, Gas Oscillation and Noise in the Explosion of Fuels. (O. Wawrziniok, Autom. Tech. Zeit., Vol. 36, No. 5, 10/3/33, pp. 136-142.) (8.13/27035 Germany.)

During explosions of fuel in a bomb, electrical apparatus recorded faint sounds before the flame reached the wall, and with a frequency corresponding to natural periods of gas vibrations in the bomb.

Thermal Calculation Compared with Observed Relations in a Diesel Engine. (H. Schor, Werft-Reederei-Hafen, Vol. 14, No. 8, 15/4/33, pp. 106-110; No. 9, 1/5/33, pp. 119-123.) (8.13/27036 Germany.)

Elaborate thermo-chemical relations are applied to calculations of heat transformations. Corrections are introduced for variable specific heats, heat losses, etc.; the formulæ are modified by the introduction of empirical coefficients, and good general fits are finally obtained with observed temperatures, pressures, and heat relations.

Comparisons are made with the experimental results of Neumann, Lutz and Pflaum. The two last show substantial agreement and the discrepancies are accounted for by differences in assumptions as to dissociation, specific heat, and accumulation of errors in the elaborate graphical processes employed.

The Upper Pressure Limit in the Chain Reaction between Hydrogen and Oxygen. (G. H. Grant and C. N. Hinshelwood, Proc. Roy. Soc., Vol. 141, No. A.843, 3/7/33, pp. 29-40.) (8.13/27037 Great Britain.)

The influence of hydrogen/oxygen ratio, inert gas, temperature and surface and diameter of vessel on the upper pressure limit of the low pressure explosion of hydrogen and oxygen has been investigated.

The authors hold that the results are inconsistent with surface adsorption relationships or differing thermal conductivities, but can be accounted for by branching chain reactions becoming de-activated in ternary collisions.

Engines—Design and Performance

Light Aeroplane Engines. (W. Kamm, Z.V.D.I., Vol. 77, No. 22, 3/6/33, pp. 593-595.) (8.20/27038 Germany.)

The power of the Argus As.8 series has been increased from 90 h.p. at 1,400 r.p.m. to 155 h.p. at 2,350 r.p.m., and of the As. 10 series from 220 h.p. at 2,000 r.p.m. to 270 h.p. at 2,150 r.p.m.

The Hirth H.M.60 gives 70 h.p. at 2,150 r.p.m. and the H.M.150 gives 160 h.p. at 2,250 r.p.m. There is a corresponding reduction in specific weight to less than 1 kg./h.p.

Constructional details are given with two photographs and a sectional sketch.

Influence of Atmospheric Conditions on Engine Performance. (H. Oestrich, Autom. Tech. Zeit., Vol. 36, No. 9, 10/5/33, pp. 226-230, and No. 10, 25/5/33, pp. 270-274. D.V.L. Report No. 315.) (8.22/27039 Germany.)

Reference is made to U.S.A. experimental work on the influence of atmospheric pressure and temperature on engine performance. An elaborate discussion is given of the numerous factors entering into the problem.

The brake h.p. is taken as the experimental datum, with tacit recognition that indicated h.p. is unreliable in the present stage. Curves showing the experimental relations between brake h.p. and atmospheric conditions are compared with various empirical relations such as variations of temperature and square root of temperature. It is considered that no determinate relations between b.h.p. and atmospheric conditions can be formulated. Application of the method to Diesel engines is discussed.

Junkers Aeroplane Engine Supercharger. (R. Schulz, Luftwacht, No. 5, May, 1933, pp. 169-172.) (8.235/27040 Germany.)

The centrifugal fan is driven by means of oil pressure applied to a gear wheel pump. The leakage in the pump can be controlled and in this way variable fan speed obtained.

Air Compression with Temperature Rises above Adiabatic with Special Reference to Airplane Superchargers. (S. A. Moss, Aeron. Eng., Vol. 5, No. 1, Jan.-March, 1933, pp. 35-43.) (8.235/27041 U.S.A.)

The study of blower performance is confused by the use of the term "efficiency" without clear definition. Such terms as "temperature efficiency," "shaft efficiency," "adiabatic compression efficiency," refer to very different ratios but are often used indiscriminately.

Four references.

"Jumo 5" Heavy Oil Engine. (Flugsport, Vol. 25, No. 13, 21/6/33, pp. 262-264.) (8.25/27042 Germany.)

Junkers have produced a smaller edition of the well-known "Jumo 4," rated at 420 h.p. continuous output on a specific weight of 2.6lb. per h.p. The general layout follows the previous design.

Notes on Petrol and Diesel Engines. (H. R. Ricardo, J.R. Aer. Soc., Vol. 37, No. 270, June, 1933, pp. 509-546.) (8.205/27043 Great Britain.)

The main problems discussed were the wear of cylinder liners of carburettor engines and the cracking of white metal big end bearings in the case of Diesel engines. A number of engine designers and users contributed views. It appeared that corrosion due to fuel is largely responsible for the wear, whilst the cracking is in some way associated with the rapid rise of pressure of the Diesel cycle.

Storage Battery Grids. (G. W. Vinal, D. N. Craig and C. L. Snyder, Bur. Stan. J. Res., Vol. 10, No. 6, June, 1933, pp. 795-808.) (8.28/27044 U.S.A.)

The effect of antimony in producing excessive sulphation of negative plates in storage batteries was investigated. Twenty cells with lead plates containing various proportions of antimony and cadmium immersed in sulphuric acid were subjected to 115 charging and discharging cycles. The increase in weight of the negative plates was measured and the condition of the positive plates was observed.

The use of pure lead positive plates was found to improve the life of the cell and the uniformity of voltage by decreasing the sulphation of the negative plates.

Numerous experimental data are given in eight tables.

Nineteen references.

The Torsion of Crankshafts. (R. Grammel, Ingenieur Archiv, Vol. 4, No. 3, June, 1933, pp. 287-299.) (8.36/27045 Germany.)

The torsional couple on a crankshaft is applied by the thrust on the cranks of the connecting rods. In the usual mathematical investigation the twisting couple is considered as applied at the free ends of the shaft, an assumption which may lead to considerable error in estimating the stiffness of the shaft.

D.V.L. Torsional Strain Recorder. (H. Lürenbaum, Z.F.M., Vol. 24, No. 7, 13/4/33, pp. 199-202.) (8.36/27046 Germany.)

An installation for measuring and recording at a distance torque strain on a length of shaft has been designed by the D.V.L. A technical description is given, with detailed end and side sketches and three photographs.

Record diagrams are scratched by a steel and diamond point on a uniformly moving strip. Calibration is discussed and three diagrams, enlarged about 16 times, are reproduced and show torque oscillations in considerable detail.

Improvements and applications are suggested.

Engines—Cooling

Convection of Heat from Plates and Cylinders in a Stream. (N. A. V. Piercy and H. F. Winny, Phil. Mag., Vol. 16, No. 105, Aug., 1933, pp. 390-408.) (8.40/27047 Great Britain.)

Assuming constant thermometric conductivity and specific heat capacity, and neglecting viscosity, Boussinesq's expression for steady two-dimensional flow becomes linear and solutions may be built up by the usual methods.

In the present paper the solution takes the form of an integral equation, the discussion of which, in reference to assumed boundary conditions for flat plates and cylinders, forms the bulk of the paper.

Comparison with King's experiments is shown graphically. There are considerable difficulties of interpretation.

Seven references.

Research on Low Drag Cowlings—Bristol Aeroplane Co. (Airc. Eng., Vol. 5, No. 55, Sept., 1933, pp. 209-212.) (8.426/27048 Great Britain.)

The introduction of supercharging and gearing down of airscrew speeds raised special problems in air-cooled engines, which were covered by U.S.A. investigations.

An account is given of the full-scale work carried out in conjunction with Messrs. Vickers. Sectioned diagram sketches show details of fixing with relative wind and speed distribution along the cylinder and disposition of cowlings.

Tables of qualitative results are given and recommendations are made.

Heat Transfer during the Flow of Viscous Fluid in Tubes. (N. Jakob and H. Eck, F.G.I., Vol. 3, May-June, 1932, pp. 121-126.) (8.444/22.2/27049 Germany.)

Experiments of Holda on the warming of oil in a tube heater disagree with the mathematical expression of Graetz. The actual measured heat transfer and temperature distribution are affected by a compensatory radial flow of the oil due to viscosity differences.

Engines—Lubricants and Lubrication

Measurement of Thickness of Lubricating Film in Bearings. (H. Hoake, Z.V.D.I., Vol. 77, No. 14, 8/4/33, p. 381.) (8.540/27050 Germany.)

A description is given of test apparatus with a conical shaft and bearing. The adjustment of the clearance can be read to 10^{-5} cm., and it is stated that lubrication is maintained down to a clearance of 10^{-4} cm.

The apparatus was designed without knowledge of the Prandtl apparatus (see Abstract No. 26060).

A Contribution to the Theory of Film Lubrication. (A. M. Robb, Proc. Roy. Soc., Vol. 140, No. A.842, 1/6/33, pp. 668-694.) (8.580/22.10/27051 Great Britain.)

The fundamental equation of Reynolds is modified to take into account the extent of the oil film, which is not necessarily equal to the length of the brass. With this modification it is possible to obtain agreement between experimental and calculated values of load carrying capacity and eccentricity locus.

Engines—Fuels

Application of Raman Spectra and Ultra Violet Absorption to the Identification of Hydrocarbons. (A. Andant, Pub. Sc. et Tech., No. 21, 1933.) (8.640/27052 France.)

The Raman spectra are examined with a photo-micrometer, and results for a number of fuels are given. It appears that mixtures of fuel can be analysed under certain conditions. The ultra-violet absorption bands are capable of determining the relative purity of a hydrocarbon, but are not applicable to the analysis of fuel mixtures.

Grading Fuels for Aeronautical Use. (W. W. White, Aeron. Eng., Vol. 5, No. 2, April-June, 1933, pp. 97-99.) (8.640/27053 U.S.A.)

A vocabulary with definitions is given for use in drawing up specifications of fuel. Difficulties met with in drawing up specifications are quoted for Navy, Army and civil experience.

A list of 19 commercial and experimental fuels is tabulated with symbols indicating the appropriate specification.

Quality and Economics of Aviation Fuel. (G. G. Oberfell, Aeron. Eng., Vol. 5, No. 2, April-June, 1933, pp. 79-87.) (8.640/27054 U.S.A.)

The physical properties of fuels are discussed and distillation characteristics are shown graphically. A graphical method is given for deriving vapour pressure characteristics from the distillation curves of the American Society for Testing Materials, and comparative calculated and observed values are given for 43 fuels in a numerical table.

Octane number, anti-knock characteristics, and gum content determination are discussed, and fuel specifications are given in tabular form.

Twenty-five references.

Effect of Gasoline Volatility on Miscibility with Alcohol. (O. C. Bridgeman and D. W. Querfeld, Bur. Stan. J. Res., Vol. 10, No. 6, June, 1933, pp. 841-850.) (8.640/27055 U.S.A.)

Increase in volatility of light motor spirit produces marked decrease in the critical temperature of solution with ethyl alcohol. Specifications by distillation temperatures and percentages of 21 gasolines are given, and of 31 aqueous solutions, with from 1 to 8 per cent. water, with specific gravities. A wide range of mixtures was examined, and the critical solution temperatures are given in tables and graphically.

One reference.

Effects of Pressure Piping on Fluid Injection. (C. W. Lawson, J.R. Aer. Soc., Vol. 37, No. 272, Aug., 1933, pp. 694-702.) (8.684/27056 Great Britain.)

The elasticity of fuel and pipe create a lag in delivery which increases with pipe length. Photographs and sketches show mechanical details and pump delivery diagrams show the delivery with a marked increase of lag as the pipe length increases. Numerous partial influences require further investigation.

Engines—Injection Systems

The Thermal Aspects of Carburation with Special Reference to the Vapourisation of Ethyl Alcohol. (J. Small, Phil. Mag., Vol. 16, No. 106, Sept., 1933, pp. 641-656.) (8.701/27057 Great Britain.)

Total heat/mixture-ratio and total heat/entropy are plotted graphically. The importance of preheating alcohol fuels is demonstrated. Starting is facilitated by suitable throttling control and by large thermal capacity in the induction system. The detrimental effect on subsequent ignition of incomplete thermal equilibrium during compression is mentioned.

The Behaviour of Spring Loaded Injection Nozzles of Oil Engines. (O. Lutz, Ingenieur Archiv, Vol. 4, No. 2, April, 1933, pp. 153-168.) (8.705/27058 Germany.)

The mathematical investigations and experiments were carried out on a standard Bosch spring-loaded nozzle. The control of the needle valve depends both on the elastic properties of the fluid and on the spring constants. The working frequency of the needle is about double that under spring control only, and care must be taken in design that the component parts do not lose contact—with consequent excessive wear.

Engines—Exhaust Systems

Silencing Motor Car Exhausts. (M. Kluge, Autom. Tech. Zeit., Vol. 36, No. 7, 10/4/33, pp. 192-196, and No. 9, 10/5/33, pp. 244-249.) (8.721/27059 Germany.)

The intensity of sounds in a busy street is taken as 50 phons, and it is considered that the intensity of exhaust noise should not exceed 70 phons at five metres. The elementary principles of acoustic filters are stated. An assumed pressure wave form is analysed into its "sound spectrum," the effect of an appropriate combination of acoustic filters is discussed, and elementary mathematical relations are obtained.

A numerical example is worked out and the damping shown as a function of frequency. A chamber volume of 4,300 cm. gave a damping of 17 phons, and of 1,000 cm. only 3 phons. The effect with three uniform damping chambers is compared with that of three staggered chambers.

It is concluded that the necessary damping to 70 phons is attainable.

Eight references.

Engines—Gears

Manufacture of Farman Airscrew Reduction Gear. (Tech. Aéron., No. 127, 1933, pp. 62-72.) (8.761/27060 France.)

The main shaft of the gear is made of chrome-nickel molybdenum steel, and the gear wheels of high tensile case-hardening chrome-nickel steel. Details of the case-hardening process are given.

Fluid Gears. (W. Bauer, Autom. Tech. Zeit., Vol. 36, No. 10, 25/5/33, pp. 258-262.) (8.761/27061 Germany.)

In hydraulic gears of the Hele-Shaw type there are considerable leakage losses. The author gives experimental evidence that spring-loaded poppet valves would control the oil flow effectively at high speed and reduce the leakage loss in gears of this type.

Armament

Field of Fire in an Aeroplane. (L. Kirste and L. Favre, L'Aéron., No. 168, May, 1933, pp. 117-119.) (9.17/27062 France.)

The authors state that the importance of measuring field of fire is a recent idea. The stereographic projection of a hemisphere is considered as the most consistent, and transformation to projections on a cube are discussed.

Projections from four different positions are reproduced separately and superposed to give a composite figure which takes account of the possible changes of position.

One reference.

Field of View of Hanriot 110. (L'Aéron., No. 168, May, 1933, p. 107.) (9.17/27063 France.)

A technical description includes projection on the sides of a cube of the solid angles of view with the pilot's head in two positions—central and 20 cm. to the right.

Materials—Characteristics

Stainless Steel in Aircraft Construction. (E. J. W. Ragsdale, Aeron. Eng., Vol. 5, No. 2, April-June, 1933, pp. 89-95.) (10.102/27064 U.S.A.)

The elementary metallurgy of an alloy suitable for structural work is discussed to show the limitations under which desirable physical properties are maintained during fabrication and welding. Photographs are given of welds of built-up component parts of wings and ribs, of a boat hull in four stages of assembly, and of a complete seaplane structure. Costs are discussed.

Creep and Structural Stability of Nickel-Chromium Steels at 870°C. (W. A. Tucker and S. E. Sinclair, Bur. Stan. J. Res., Vol. 10, No. 6, June, 1933, pp. 851-862.) (10.104/27065 U.S.A.)

The apparatus for testing under high temperatures is shown in a sectioned diagrammatic sketch. Specifications of 26 alloys are tabulated. A mass of creep data is given showing creep after 500-700 hours as a function of temperature.

Comparison is made with previous tests at 538°C. Changes of structural grain are shown in 12 micro-photographs and are remarkably slight.

A New Light Alloy. (Autom. Tech. Zeit., Vol. 36, No. 10, 25/5/33, p. 269.) (10.231/27066 Germany.)

The Interressengemeinschaft Farbenindustrie have introduced under the trade name of "hydronalium" a new Al/mg. alloy ($\rho = 2.6$) with forging properties similar to duralumin but with higher resistance to corrosion.

Aluminium Alloys in Aircraft Construction. (C. F. Nagel and G. D. Hogland, Aeron. Eng., Vol. 5, No. 2, April-June, 1933, pp. 75-78.) (10.231/27067 U.S.A.)

Figures are given to show steady increase up to a guaranteed yield point of 30,000 lbs., and tensile strength 60,000 lbs., for duralumin and its variants as manufactured in U.S.A. Alclad has set an entirely new standard of resistance to corrosion.

Practice in riveting and welding is discussed briefly, and a comparative table of spot weld and rivet strength on the whole shows higher figures for welding. Applications to aeroplane construction are suggested.

In the discussion corrosion was the principal subject raised. In reply it was stated that paints and varnishes did not hold well on smooth duralumin surfaces, but that roughened duralumin surfaces were better than steel surfaces.

Influence of Initial Stress on Fatigue Strength. (P. Ludwik and J. Krystof, Z.V.D.I., Vol. 77, No. 24, 17/6/33, pp. 629-635.) (10.245/27068 Germany.)

When a variable load is superposed on a steady initial load an experimental relation is found between the initial load and the limiting variable load, the total load of rupture being the sum of the two former. The functional relation between any pair of these three quantities is shown graphically as a unicursal curve and a variety of transformation is available.

Extensive data are shown graphically and in numerical tables for 18 steels, cast irons and light and heavy alloys. Examples of the influence of corrosion and notching are given.

Twenty-eight references.

Elastic Deformation of Timber. (J. Stamer and H. Sieglerschmidt, Z.V.D.I., Vol. 77, No. 19, 13/5/33, pp. 503-505.) (10.400/23.10/27069 Germany.)

Young's modulus multiplied by the cube root of the cubic modulus and divided by the shear modulus is taken as independent parameter, and the ratio Young's modulus/shear modulus is plotted against it. The resulting locus is roughly linear for metals and timbers.

Numerical tables contain experimental values of the moduli.

Twelve references.

Glass with Internal Strains. (L. von Reis, Z.V.D.I., Vol. 77, No. 23, 10/6/33, pp. 615-618.) (10.406/27070 Germany.)

Methods of annealing glass are discussed and illustrated by sketches of the annealing apparatus and curves of cooling. The internal stress distribution is shown as a function of rate of cool and of thickness. Under certain conditions the initial strain gives higher resistance to loads.

A useful property is the shattering of the whole sheet into small particles which are less dangerous in an accident than large fragments.

Three photographs and 13 diagrams are given.

Materials—Defects and Treatment

Gases in Metals. (J. H. Scaff and E. E. Schumacher, Bell Tele. B.727, 1933.) (10.120/27071 U.S.A.)

Apart from case-hardening by the important nitriding process, the technical interest of absorption of gases in metals lies chiefly in the adverse effect on casting.

Methods of analyses and measurement of gases in metals are described, and apparatus for melting metals in high vacuum are illustrated by two photographs and a diagram. Electric melting in vacuo was developed on a manufacturing scale in Germany during the war, and vacuum furnaces of four-ton capacity are in operation. The difficulties met with and the advantages obtained are discussed.

Twenty-six references.

Spot Welding of Various Metals. (L. Ferguson, Bell Tele. B.748, 1933.) (10.140/27072 U.S.A.)

The results depend on the correct adjustment of the physical factors involved, which include electric current density and contact resistance of electrodes, electrical resistance, thermometric conductivity, cooling path and cooling surface, electrode cooling. Mechanical pressure influences the contact resistance and the welding action. The voltage, strength and duration of current are regulated to produce the best conditions.

From the metallurgical point of view, melting temperatures and mechanical strength of the alloy found are influenced by the volume and shape of the weld on the surrounding medium—air, hydrogen, water, etc.—the temperature and rate of cooling.

Sketches show different forms of electrodes and welded materials, the shape of the heated metal and the electric current lines. Specifications are given for welding various materials.

Eleven references.

Fatigue Strength of Welds. (G. Schaper, Z.V.D.I., Vol. 77, No. 21, 27/5/33, pp. 557-560.) (10.140/27073 Germany.)

A summary is given of research methods and results on welded joints by the V.D.I. and other laboratories. Numerous types of weld are indicated by sketches, with distribution of stress lines in one case. A short numerical table gives results of variable loads on beams with welded flanges. Rules are given for the permissible use of welded joints under different types of load.

Two references (see Abstract 27075).

Influence of Slag Inclusions on Electric Welds. (H. Blomberg, Z.V.D.I., Vol. 77, No. 18, 6/5/33, pp. 475-477.) (10.140/27074 Germany.)

Thirteen micro-photographs show forms of slag inclusion and distortion of films in butt welding. The effects are discussed and rules are given for avoidance of serious defects.

See Abstracts 27073 and 27075.

Fatigue Strength of Welds of Different Shape. (A. Thum and W. Schick, Z.V.D.I., Vol. 77, No. 19, 13/5/33, pp. 493-496.) (10.140/27075 Germany.)

A test piece without weld and 16 types of weld are shown in sketches. The variable load imposed was of the nature of a sine wave superposed on a constant value.

A summary is given of the effects of variations in shape on the reduction of strength. Seven photographs show welds and fractures. In general, smooth flow of stress lines through material and weld is of primary importance. The run of the stress lines is shown qualitatively for several specimens to illustrate the point.

Calculation of Spiral Springs of Rectangular Cross Section. (G. Liesecke, Z.V.D.I., Vol. 77, No. 16, 22/4/33, pp. 425-426.) (10.164/27076 Germany.)

Various approximations of the exact result are discussed and an approximate formula is selected which is stated to give sufficient accuracy for practical design.

The numerical results are given in a series of curves for different ratios of the sides and the projected radius of the spirals.

Design of Valve Springs. (F. Nixon, Aire. Eng., Vol. 5, No. 55, Sept., 1933, pp. 193-196.) (10.164/27077 Great Britain.)

The effect of surging in increasing the stresses in the material is considered briefly. When the maximum surging stresses have been brought within the permissible limit there still remains the question of local defects in the materials, which are considered by the author to be the source of most breakages.

Air Ministry specifications are quoted and charts and tables are prepared for rapid computations to determine the dimensions of the spring which will bring it within the prescribed conditions.

Harmonics in Valve Springs. (E. Lehr, Z.V.D.I., Vol. 77, No. 18, 6/5/33, pp. 457-462.) (10.164/27078 Germany.)

The stroboscopic method of observing periods is described. Numerical Table I gives an analysis by Runge's method of D.V.L. observed inlet and outlet valve motions to the 12th harmonic for three spring settings; Table II similarly for American experiments up to the 30th harmonic. The differential equation is formed and solved in the usual manner.

The damped reflections of a wave are exhibited graphically for an aeroplane engine at maximum speed. A three-dimensioned model exhibits a surface of amplitudes intuitively.

Eight references.

Protection of Timber from Flames. (Z.V.D.I., Vol. 77, No. 16, 22/4/33, p. 428.) (10.420/16.05/27079 Germany.)

A specification is given of some protective materials produced commercially, with a brief account of their action when the treated timber is exposed to flaming gases.

Instrument for Measuring Thickness, Compressibility and Resilience of Textiles, etc. (H. F. Schiefer, Bur. Stan. J. Res., Vol. 10, No. 6, June, 1933, pp. 705-713.) (10.424/27080 U.S.A.)

A disc, one inch in diameter, is pressed on a sheet of material laid on a plane table, the pressure and compression being indicated by dials. Eight experimental stress strain diagrams are drawn and numerical results are tabulated for 35 materials.

Three references.

Raw Rubber as Material of Construction. (A. Frank, Z.V.D.I., Vol. 77, No. 15, 15/4/33, p. 400.) (10.428/27081 Germany.)

Stress strain diagrams are shown for raw rubber and for sheets made up with alternate laminations of cork and papier maché. Other properties are given in a table.

Three references.

"Faudi" Pneumatic Shock Absorber. (Flugsport, Vol. 25, No. 6, 15/3/33, pp. 124-127.) (10.444/27082 Germany.)

In shock absorbers of combined oil and pneumatic type, troubles may arise from high viscosity at low temperature, from leakage or from corrosion. In the "Faudi" pneumatic absorber no oil is used and the weight is relatively small. Rubber packing rings render the air leakage small, with re-inflation at long intervals. It has passed successful tests at the D.V.L. and is fitted to the Heinkel He. 70.

Characteristics of Shock Absorbers. (H. O. Fuchs, Autom. Tech. Zeit., Vol. 36, No. 7, 10/4/33, pp. 169-172.) (10.444/27083 Germany.)

Single and double acting shock absorbers are shown in sectional diagrams. Pressure-stroke diagrams are shown for both types for three different rates of strain. Pressure-stroke characteristics are also given for different settings and rates of strain.

Seven references. See Abstract 27082.

Temperature Stress in Walls and Slabs. (N. S. Boulton, Phil. Mag., Vol. 16, No. 103, July, 1933, pp. 145-163.) (10.90/27084 Great Britain.)

Expressions are formed for temperature strains and corresponding internal stresses in the simple cases considered, a simple temperature distribution being assumed.

Numerical examples are worked out and distributions of temperature and stress are shown graphically.

Contribution to the Study of Corrosion of Iron and Steel. (J. Aubert, Pub. Sc. et Tech., No. 23, 1933.) (10.125/27085 France.)

The work is an extension of the researches of Evans'. Oxidising corrosion is largely governed by differences in oxygen concentration over the surface of the metal. The metal surface is in various states of activation and the resulting corrosion can be controlled by the presence of hydroxyl ions.

Protection Against Corrosion on the German Railways. (O. Lindermayer, Z.V.D.I., Vol. 77, No. 15, 15/4/33, pp. 385-392.) (10.125/27086 Germany.)

Climatic conditions are considered in different parts of Germany. A wide range of experience, particularly with steel construction is discussed.

Tabular specifications of treatment are given and costs of maintenance are shown graphically.

Fourteen references.

Electrochemical Oxidation and Protection of Iron and Duralumin in Aerated Saline Solutions. (E. Herzog, Pub. Sc. et Tech., No. 19, 1933.) (10.125/10.262/27087 France.)

A study of the polarisation of certain electrolytic cells shows that certain impurities act as accelerators or decelerators of corrosion, in a manner which accounts for the difference between the action of sea water and of salt solutions.

Influence of Heat Treatment on Corrosion of Rolled Aluminium Alloys. (Z.F.M., Vol. 24, No. 10, 29/5/33, pp. 284-285.) (10.260/27088 Germany.)

A specification is given of heat treatments applied in tests on duralumin and lautal.

The results of corrosion tests on the duralumin specimen are shown graphically in relation to the heat treatment temperature after 0, 2, 4, 6, 8 and 10 days' corrosion treatment. The curve of ultimate strength before corrosion treatment remains nearly constant for heat treatment temperatures from 18° to 145° and then falls over 10 per cent. for 180° re-heat temperature; the remaining curves are systematically lower as corrosion time increases and all show a marked dip for annealing temperature—135°—with recovery at about 160°.

Corrosion of Metals—Causes and Effect. (G. Guzzoni, L'Aerotecnica, Vol. 13, No. 6, June, 1933, pp. 714-744.) (10.262/27089 Italy.)

The author supports the differential aeration theory of Evans with a numerous selection of examples of aluminium alloys illustrated by photographs. The conclusions lead to the usual precautions and a summary is given of practice in producing resisting alloys of aluminium and in applying protective processes and coverings.

Duralumin Applied to Aircraft Construction. (W. H. Lewis, J.R. Aer. Soc., Vol. 37, No. 272, Aug., 1933, pp. 680-693.) (10.290/27090 Great Britain.)

The metallurgical aspect is discussed with curves showing the relation between heat treatment and ultimate stress. Corrosion and corrosion experiments are surveyed and anti-corrosion treatments are specified.

The manufacturing of strip and tubes and their working into frames and hulls are briefly described and illustrated by five photographs.

Testing Apparatus and Methods of Testing

Acrogrammes by Refraction of Hot Air Filaments. (A. Lafay, Pub. Sc. et Tech., No. 24, 1933, p. 25.) (11.105/27091 France.)

The experimental mounting is described with illustrations. A number of photographs are reproduced of the optical caustics produced by a beam of light

passing through hot air filaments travelling with the wind stream. The velocity field round a plate and stationary or rotating cylinders is shown by photographic records of the hot air filaments obtained in this way.

Aerofoil in Wind Channel of Elliptic Section. (L. Rosenhead, Proc. Roy. Soc., Vol. 140, No. A.842, 1/6/33, pp. 579-604.) (11.16/27092 Great Britain.)

Prandtl's method of images, applied to circular channels, and Glauert's numerous extensions to rectangular, elliptical and other channels, are given greater unity and generality by the author's more powerful analysis.

In a previous paper the doubly infinite series of images in a rectangular channel were expressed in terms of elliptic functions (theta functions). In the present paper, suggested by Glauert's work referred to above, expressions are formed in terms of theta functions for a complex function, the real and imaginary parts of which supply the stream lines and potential lines of the motion inside an elliptic boundary containing simple vortices.

The numerical parameters are the ratio of span to focal distance and the ratio of semi-diameters, as functions of which the coefficient of induced velocity is tabulated and shown graphically by families of curves, for closed and open streams.

Seven references.

Interference by Walls of Wind Channel. (L. Rosenhead, Proc. Roy. Soc., Vol. 142, No. A.846, 2/10/33, pp. 308-320.) (11.16/27093 Great Britain.)

Reference is made to Theodorsen's paper (see Abstract 27097).

Appropriate expressions for the induced velocity near a wing represented by a vortex doublet are formed in terms of theta functions. It is shown that an additional linear term must be taken into account, which vanishes when the stream has two closed sides parallel to the span and two open sides at right angles to it, but not when the doublet is turned through a right angle. This appears to have been overlooked by Theodorsen and leads him to erroneous results. The error is disclosed on comparison with known results from Glauert's theorem that if the open and closed parts of the boundary be interchanged the interference on the doublet turned through a right angle is the same numerically but has the opposite sign.

The coefficient of induced velocity is tabulated and plotted for all possible combinations of open and closed boundaries of rectangular stream.

Interference with Aerofoils of a Channel of Rectangular Section. (H. Glauert, Reports and Memoranda No. 1419.) (11.16/27094 Great Britain.)

Reference is made to the development of expressions in elliptic functions by Terazawa and Rosenhead. Their expressions are transformed and the new expressions are tabulated to facilitate numerical calculation.

The coefficient of induced velocity averaged across the wing span is a useful parameter in obtaining approximate numerical values of sufficient accuracy and is shown graphically for square and 2 : 1 rectangular channel, as a function of span/width of channel.

Four references.

Interference with Aerofoils of a Channel of Circular Section. (H. Glauert, Reports and Memoranda No. 1453.) (11.16/27095 Great Britain.)

The interference for elliptic and uniform distribution of circulation along the span discussed by Prandtl and Rosenhead is generalised for any distribution expressed as a Fourier series.

It is shown that the corrections obtained for induced drag and induced incidence are substantially negligible for usual aerofoil sections.

Two references.

Interference with Aerofoils of Wind Channels. (H. Glauert, Reports and Memoranda No. 1470, 1932.) (11.16/27096 Great Britain.)

Using the methods of conformal transformation, the aerofoil is taken to be small and replaced by a doublet of appropriate strength. The conditions required to bring the normal velocity to rest over a given boundary and to make the normal pressure zero over the same boundary are expressed by integrals over the boundary of equal magnitude and opposite sign, provided the aerofoil is turned through one right angle in the plane of the channel section in the respective cases. In the particular case where the channel section is an ellipse the coefficient of induced velocity is calculated for closed and open channels for various ratios of semi-diameters. The results are approximate; for an aeroplane of appreciable span/stream width ratio, higher integrals are required.

Wing Interference in a Rectangular Jet. (T. Theodorsen, N.A.C.A. Report No. 461, 1933.) (11.16/27097 U.S.A.)

The author refers to solutions of various wind channel interference problems by Prandtl, Glauert, Terazawa, Rosenhead, and Sanuki and Tani, and states that the solution for a rectangular stream with free boundaries above and below and rigid boundaries at the sides remains for detailed consideration. Following the method of Terazawa approximate expressions are formed for the doubly periodic distribution of vortices and reduced to series involving hyperbolic series. Numerical values are plotted graphically. The general expressions in terms of elliptic functions are not developed.

Nine references (including Sanuki and Tani's paper—see Abstract 27098). See also Abstract 27093 for criticisms by Rosenhead.

Interference in a Wind Channel of Elliptic Section. (Sanuki and Tani, Proc. of Physico-Mathematical Soc. of Japan, 3rd Series, Vol. 14, No. 10, Nov., 1932.) (11.16/27098 Japan.)

This paper is referred to by T. Theodorsen in N.A.C.A. Report No. 461—see Abstract 27097.

The Buckling of Spars. (J. Bach, Z.V.D.I., Vol. 77, No. 23, 10/6/33, pp. 610-614.) (11.34/27099 Germany.)

A summary is given of the results of experiments in comparison with various formulæ. The load factor should be defined with reference to the buckling load and not to the actual stress in the material.

Seventeen references.

Objects and Methods of Float Research for Seaplanes. (W. Pabst, Werft-Reederei-Hafen, Vol. 14, No. 11, 1/6/33, pp. 139-147. 108 Report of Hamburg Shipbuilding Research Institute.) (11.35/27100 Germany.)

A summary of the problems arising in float design refers to the starting resistance, throwing of spray, minimising of shock in a seaway while maintaining high load factor, heading into wind when drifting—particularly in a seaway, and stability—especially under the last condition, minimum air resistance, steerability in smooth water and directional stability in light seas.

There is some recapitulation of previous work (see Abstract 26096) but much new experimental work is introduced. A description is given of the experimental tank and travelling carriage with six-component equipment for measuring shocks. Cinematograph records show splash formations at successive time intervals.

Four autograph shock records are reproduced and moments about three arcs are shown graphically for a range of speeds. A wave recorder is described and illustrated and is considered an essential item of equipment.

Eleven references.

Test Machine for Rubber Tyres. (Z.V.D.I., Vol. 77, No. 17, 29/4/33, p. 451.) (11.45/27101 Germany.)

A photograph shows a rubber-tyred wheel mounted in a twenty-ton test machine with convenient devices for applying and reading total load and internal air pressure.

Some typical test loads and pressures are given in a table.

Airships

The Present Position of Airship Construction, Especially that of Rigids. (H. Ebner, Z.F.M., Vol. 24, No. 11, 6/6/33, pp. 311-316, and No. 12, 28/6/33, p. 331. D.V.L. Report No. 323.) (12.10/27102 Germany.)

This article is largely historical. Evidence is put forward in favour of wire braced girder structure which has been a characteristic of Zeppelin airships from the beginning.

Fifty-one illustrations and 39 references.

Pressure in Airships. (W. A. Klikoff, Aeron. Eng., Vol. 5, No. 1, Jan.-March, 1933, pp. 29-33.) (12.10/27103 U.S.A.)

The article refers particularly to metal coverings in which the shape is maintained chiefly by internal gas pressure. A photograph shows a U.S. Navy metal-clad airship. Elementary pressure tension relations are given and structural advantages are indicated. The risks of puncture followed by release of pressure and deformation suggest the compromise of a rigid metal-clad dirigible.

Three references.

Artificial Pay Load for Airships. (T. L. Blakemore, Aeron. Eng., Vol. 5, No. 2, April-June, 1933, pp. 61-64.) (12.30/27104 U.S.A.)

A number of suggestions are made for improving the design and for making the most of performance possibilities. The former include pre-heating the space between outer cover and helium gas cells and maintaining the heat as long as possible by use of the exhaust, with the incidental advantage of preventing ice formation; using swivelling airscrews for dynamic lift; retracting power units not in use within the hull.

Further suggestions are:—Completing the load from auxiliary aeroplanes after the flight has begun; using uninsured load equipped with parachutes as emergency ballast.

A total addition of 19 per cent. of the total lift as pay load is estimated. Comparative data of the Shenandoah, Akron and Los Angeles are given.

Mooring and Ground Handling of a Rigid Airship. (C. E. Rosendahl, Aeron. Eng., Vol. 5, No. 1, Jan.-March, 1933, pp. 45-52.) (12.33/27105 U.S.A.)

The experience obtained from handling a succession of U.S. Navy airships is the basis of the paper. A summary is given of the problems arising in equipping, maintaining and handling large dirigibles and of the various methods employed.

Three references.

Wireless

Radiation from Antennæ as Affected by the Electromagnetic Characteristics of the Earth. (M. J. O. Strutt, Ann. d. Phys., Vol. 17, No. 4, June, 1933, pp. 376-384.) (13.30/27106 Germany.)

Assigning a uniform dielectric constant and conductivity to the earth in the neighbourhood of the antennæ the electric and magnetic rays emitted are refracted at the earth's surface in a known manner.

The resultant field is expressed as an integral and an asymptotic approximation gives results in agreement with Weyl and Funk for a vertical electrical dipole and new formulæ for horizontal electrical and magnetic dipoles.

Six references.

Low Power Radio Transmitters for Broadcasting. (A. W. Kishpaugh and R. E. Coram, Bell Tele. B.722, 1933.) (13.31/27107 U.S.A.)

From authors' abstract:—The characteristics and more interesting features of a new line of transmitters covering the range of output from 100 to 1,000 watts are described. The basic unit is a 100-watt transmitter employing grid bias modulation which is novel in so far as American broadcast practice is concerned. The housings allow complete access for adjustment and maintenance.

Radio Range Beacon System—Problem of Night Effects. (H. Diamond, Proc. Inst. Rad. Eng., Vol. 21, No. 6, June, 1933, pp. 808-832.) (13.4/27108 U.S.A.)

Author's abstract:—A new antenna system is described for use at radio range beacon stations which eliminates the troublesome night effects hitherto experienced in the use of the range beacon system. Considerable data, comprising ground and flight measurements, are given on both aural and visual type range beacons using the present loop transmitting antennas, which show the severity of the night effects encountered.

Because of the magnitude of these effects, particularly in mountainous country, the range beacon course often becomes of no value beyond about thirty miles from the beacon station. With the new antenna system developed, referred to as the transmission line system, the beacon course is satisfactory through its entire distance range, the night effects becoming negligible.

Experimental data are given comparing the performance of the transmission line and loop antenna systems under nearly identical conditions. The paper includes a theoretical analysis of the phenomena underlying the occurrence of night effects and how to eliminate them.

Radio Range Beacon Free from Night Effects. (H. A. Chinn, Proc. Inst. Rad. Eng., Vol. 21, No. 6, June, 1933, pp. 802-807.) (13.4/27109 U.S.A.)

Author's abstract:—A radio range beacon, suitable for the guidance of aircraft along established airways, which is entirely free from atmospheric variations or "night effects," is described. Advantage is taken of the phenomenon that waves of frequencies higher than 30 megacycles per second, or thereabouts, are not usually refracted back to the earth by the Kennelly-Heaviside layer. Multiple path transmission, variation in signal intensity and in polarisation are thus avoided.

A four-course aural beacon operating on 34.6 megacycles per second was employed for the experimental work. Results and applications are discussed.

An Efficient Miniature Condenser Microphone System. (H. C. Harrison and P. B. Flanders, Bell Tele. B.679, 1932.) (13.5/27110 U.S.A.)

From authors' abstract:—It has been shown recently that microphones and contiguous amplifiers distort the sound field in which they are placed by reason of their size and the cavity external to the diaphragm of the microphone.

The paper describes a laboratory model of a Wente type condenser microphone of high efficiency and an associated coupling amplifier, which are of such small size that reflection and phase difference effects are of negligible importance within the audible frequency range, while the cavity is so proportioned that its resonance effect is an aid rather than a detriment to uniformity of response in a constant sound field.

Nine references.

Detection of Two Modulated Waves by Linear Rectifier. (C. B. Aiken, Bell Tele. B.730, 1933.) (13.5/27111 U.S.A.)

The action of an ideal linear rectifier is discussed mathematically. The expressions for two voltage waves impressed on a rectifier are combined into a single expression. The converse problem is attacked by expressing the composite wave in a series of derivatives of zonal harmonics from which the harmonics are extracted by one of two alternative methods. The analysis is arranged for convenient computation and interpretation and numerical examples are shown graphically.

Ten references.

Behaviour of Electron Tubes with a Magnetic Anode in a Magnetic Field. (H. A. Schwarzenbach, Ann. d. Phys., Vol. 17, No. 4, June, 1933, pp. 385-400.) (13.5/27112 Germany.)

A time-change in the electron stream takes place under a magnetic field parallel to the axis of symmetry of a triode. This is ascribed to changes in the magnetic field produced by temperature magnetic effects on the nickel anode cylinder. The relation between energy of the electron bombardment corresponding to the anode temperature and the magnetic field within the anode is investigated.

Magnetic fatigue and restoration are exhibited graphically as functions of time in five diagrams. Fatigued or unfatigued characteristics are also shown as functions of the voltage.

Twenty-three references.

Spread of Electromagnetic Fields Along River Courses. (V. Fritsch, H.F. Technik., Vol. 41, No. 3, March, 1933, pp. 100-104.) (13.6/27113 Germany.)

Communication along river courses should be within the 40-80 m. band, the spread of which is favoured by the river, especially at considerable distances from the sender.

Short-Wave Transmission from New York to South America. (C. R. Burrows and E. J. Howard, Bell Tele. B.720, 1933.) (13.6/27114 U.S.A.)

From authors' abstract:—A year's survey of transmission conditions between New York and Buenos Aires, in the short-wave radio spectrum exhibiting the received field strength as a function of time of day and frequency, shows that frequencies between 19 and 23 megacycles were best for daytime transmission and those between 8 and 10 megacycles for night-time transmission. Frequencies higher than about 30 megacycles could not be received.

Transmission Lines for Short-Wave Radio Systems. (E. J. Sterba and C. B. Feldman, Bell Tele. B.683, 1932.) (13.6/27115 U.S.A.)

From authors' abstract:—The requirements imposed on transmission lines by short-wave radio systems are discussed and the difference in the requirements for transmitting and receiving purposes is emphasised. The concentric tube line is particularly valuable in receiving stations where great directional discrimination is involved and low noise and static pick-up is required.

Excellent agreement between calculations and measurements is found for the high frequency resistance of concentric lines, using the asymptotic skin effect formula of Russell. Other losses in correctly designed concentric tube lines are found to be negligible.

Practical aspects of line constructions such as joints, insulation and provision for expansion with increasing temperature are discussed. Some difficulties encountered in transmission line practice, such as losses due to radiation, reflections from irregularities, effects of weather and spurious couplings between antenna and line are discussed.

Rectifier Cells for Measurements of Daylight (H. H. Poole and W. R. G. Atkins, Sci. Proc. of Roy. Dublin Soc., Vol. 20, Nos. 29-36, April, 1933, pp. 537-546.) (13.7/27116 Great Britain.)

Five types of cell were calibrated and the photo-electric characteristics are shown graphically. The temperature effect on the characteristics is shown in a second diagram. The sensitivity is shown as a function of wave-lengths in the range of visible rays. The characteristics of all but one type cell changed from day to day.

Subject to suitable calibration, with re-calibration from time to time, the cells examined are suitable for comparative records of intensity of daylight.

Ten references.

Application of a Pile of Electrical Semi-Conducting Material to Pressure Measurements. (W. Glamann and H. Triebnigg, F.G.I., Vol. 4, No. 3, May-June, 1933, pp. 137-146.) (13.81/27117 Germany.)

The electrical conductivity of a pile of thin discs of carbon is a function of the end pressure. This is applied to the construction of pressure indicators shown in section sketches. Calibration curves are given and sources of error are discussed.

Specimen indicator diagrams obtained from a Diesel motor are compared with those obtained by a spring controlled indicator.

Eight references.

Photography

Photogrammetry of Landing Speeds. (V. C. Finch, Aeron. Eng., Vol. 5, No. 1, Jan.-March, 1933, pp. 23-27.) (14.28/14.40/27118 U.S.A.)

Cinematograph records of an aeroplane landing are reduced by the usual methods of projective geometry. Details of the apparatus are given and the somewhat elaborate precautions and corrections are discussed. The error is estimated at about 1 per cent. Specimen films are reproduced.

Nine references.

Determination of Aeroplane Path by Photogrammetric Methods and by Cinematograph Records. (W. Schnittger, Z.F.M., Vol. 24, No. 9, 15/5/33, pp. 241-249.) (14.28/14.40/27119 Germany.)

Two types of apparatus are described. The first consists of a camera with a fixed plate and an orientable lens. The circular image formed by each exposure is about 1/150th of the plate surface, and with some overlapping about 20 images in the breadth and 30 in the length of the plate could be formed, each showing the position of the aeroplane. The angular position is determined from the position of the focus with respect to the plate, and the distance by the size of the image of the aeroplane, so that the aeroplane must fly approximately overhead. For rolling and looping the use of two such cameras is suggested.

The second type consists of a cinematograph camera mounted on a theodolite. The focal axis is parallel to that of the telescope. One instrument is mounted at each end of a base line. The film records the position of the aeroplane and the altitude and azimuth vernier readings. A correction is readily made for the distance of the aeroplane image from the cross wires. The two altitudes and two azimuths give a redundant reading, which may be used as a check.

In a variant of the second method the times are determined separately. An elementary account is given of the geometry involved and method of reducing observations.

Errors of observation are discussed, particularly with reference to high speed determination. A technical description of the equipment of a suitable base line is illustrated by sketches.

The Film in Engineering. (H. Wimperis, Engineer, Vol. 156, No. 4053, 15/9/33, p. 255. British Association—Section G (Engineering), 8/9/33.) (14.28/27120 Great Britain.)

Three methods of applying cinematograph records to technical measurements were discussed, the recording of simultaneous readings of a battery of indicating instruments, the recording of the motion of any object on films afterwards subjected to measurement, and the use of slow motion films to study motions which were too rapid for the eye to analyse.

Cinematic Studies of the Compass in an Aeroplane, 1931. (A. Ritscher and W. Immler, Z.F.M., Vol. 24, No. 7, 13/4/33, pp. 185-193, and No. 8, 28/4/33, pp. 213-221.) (14.28/6.501/27121 Germany.)

Four compasses were installed on the compass board and their indications were recorded by cinematograph, while another cinematograph recorded the topography of the ground below the aeroplane. A careful analysis is given of the difficulties of mounting, synchronising and reducing the film records. A specimen table of entries of readings is given and readings are plotted in seven charts with reduced relative readings and with straight lines representing the true bearing. The compass errors are plotted separately on the same diagram and show average values of less than 4° with jumps and nearly 10° after sudden changes of course.

Damped oscillations about the principal axis with an initial displacement of 90° are shown graphically for four types of compass, the period varying from 9-16 seconds. The figure also shows damped oscillations about E.-W. and N.-S. areas. The lower figure was obtained by using a needle of small mass, with a large restoring moment. Further curves show lags in steady turns of specified angular velocity, 2° per sec., and oscillations under arbitrary disturbance. Numerical tables contain the detailed readings. Applications to compass design are discussed and rules are given for designers. Experiments with aperiodic compasses are in view and needles with two bearings are receiving attention.

Acoustics, Noise Reduction, Etc.

Determination of Altitude. (P. Léglise, L'Aéron., No. 169, June, 1933, pp. 128-134, and No. 170, July, 1933, pp. 160-170.) (15.0/27122 France.)

A survey is given of methods and apparatus and includes variations in electric capacity, interference of radio waves, reflection of directional radio waves and reflection of infra red rays. Acoustical methods are discussed at some length. The principal causes of error are variations in temperature, aeroplane and wind velocities, control of times of emission and reception, interference between emitter and receiver, and irrelevant noises.

A photograph shows an elaborate sound equipment with multiple emitters, apparently as an example to be avoided. Technical descriptions are given of representative installations and are illustrated by numerous figures and extracts from patent specifications, and examples of records are reproduced.

The paper is a useful review of the present position of altitude determination below, say, 300 metres above the immediate ground level, and has an obvious importance in reference to blind landings.

Meteorological Acoustics. (W. S. Tucker, Jrnl. Met. Soc., Vol. 59, No. 250, July, 1933, pp. 203-216.) (15.2/27123 Great Britain.)

The problem of sound transmission through the atmosphere is discussed in terms of the physical relations involved.

With a normal lapse rate, in still air sound is refracted upwards from a source on the ground in catenary curves, the envelope of such curves constituting

an acoustical bowl outside which no sound penetrates. Conversely, no sound produced at a point lying outside the acoustic bowl through the observer's position can reach him.

Wind gradients and changes in the lapse rate distort the bowl from the catenary form. An inversion of the lapse rate may refract the sound range back to the earth, leaving intermediate " deaf " regions.

Elementary mathematical expressions for these effects are formed and tables of numerical values are given. Water vapour content has very sensible effects on the acoustical properties of the atmosphere.

Knowledge of the meteorological conditions is necessary for sound ranging of unknown sources such as guns and aeroplanes. Conversely, sound ranging observations between known points contribute to knowledge of the state of the atmosphere.

Measurement of Acoustical Impedance. (P. B. Flanders, Bell Tele. B.678, 1932.) (15.26/27124 U.S.A.)

The electro-magnetic analogy is applied and expressions and equations are formed in complex algebra. Numerical solutions are shown graphically. The observed impedance characteristics are in general oscillatory about the calculated values as means.

Nine references.

Noise in Aircraft. (S. Capon, Engineer, Vol. 156, No. 4053, 15/9/33, p. 255. British Association—Section G (Engineering), 8/9/33.) (15.26/27125 Great Britain.)

Reference was made to investigations in progress at the National Physical Laboratory, the Royal Aircraft Establishment and the Air Defence Establishment. The reduction of noise in aircraft cabins was specially considered and a reduction had been obtained from 80 decibels to 70 decibels, approximately the intensity in a railway carriage with open windows. Instrumental equipment was described in some detail.

Mr. Wimperis (Director of Scientific Research, Air Ministry) gave acknowledgment of the work done. The reduction of noise on air liners had rendered the use of cotton wool in the ears unnecessary to passengers in civil aircraft and he considered that the growth in passenger air traffic was largely due to this improvement in comfort. The silencing of wireless cabins in naval and military aircraft was an important application. In the campaign for abatement of noise attention might well be directed to pneumatic drills and motor cycles, which were more objectionable than the maligned aeroplane.

Dr. Tucker discussed the imperfection of the ear in comparison with instrumental measurements and the difficulty of forming quantitative judgments of auditory sensations.

Propagation of Sound Along Airscrew Wake. (E. T. Paris, Phil. Mag., Vol. 16, No. 103, July, 1933, pp. 61-64.) (15.26/27126 Great Britain.)

The intensity of the exhaust of a Rolls-Royce 12-cylinder Condor exhausting in banks of six cylinders through two exhaust pipes was explored by the same method as in the previous paper (see Abstract 26030). M. P. Hart's theory is applied to give a polar curve of intensity along different directions of the second harmonic.

Two sets of observed values are plotted on a separate polar diagram and show heavy divergence from the calculated diagram, in particular smaller intensity down stream and higher intensity transversely. This is attributed to acoustical refraction in the wake.

Seven references.

Accidents and Precautions

Lightning. (A. O. Austin, Aeron. Eng., Vol. 5, No. 1, Jan.-March, 1933, pp. 13-21.) (16.30/27127 U.S.A.)

A high voltage installation was set up by the Ohio Insulation Company, capable of discharging at 1,500,000 volts. Photographs show discharges passing through balloon, airship and aeroplane models and full size aeroplanes and balloon cars. The types of damage are classified and discussed.

Aircraft—Unorthodox

Tendencies in Aeroplane Development. (M. Schrenk, Z.F.M., Vol. 24, No. 10, 29/5/33, pp. 273-279.) (17.0/27128 Germany.)

A descriptive survey is given of tendencies in design, including tail-less aeroplanes, autogyros and helicopters.

Twenty references.

Rocket Propulsion. (H. Chatley, J.R. Aer. Soc., Vol. 37, No. 272, Aug., 1933, pp. 723-728.) (17.20/27129 Great Britain.)

The elementary thermodynamics and dynamics are worked out and numerical examples are computed.

Twenty-four references.

Test Performance of the Focke-Wulf "Ente" (Canard)—Introduction by H. Focke. (W. Hubner, Z.F.M., Vol. 24, No. 8, 28/4/33, pp. 223-230, and No. 9, 13/5/33, pp. 255-258. Test Report No. 317 Report of D.V.L.) (17.30/27130 Gemany.)

The designer gives a brief account of the advantages of the tail-first type, particularly freedom from stalling and from pitching over on the ground. The report gives a full technical specification of the aircraft and a mass of performance data in graphical form.

A descriptive analysis summarises the behaviour of the aeroplane under a wide variety of air conditions. The total flight distance was about 6,000 km.

The report is an important guide to the somewhat controversial subject of relative merits as compared with the more usual type with tail plane.

Cloud Formation and Gliding. (G. T. Walker, J.R. Aer. Soc., Vol. 37, No. 272, Aug., 1933, pp. 657-680.) (17.40/27131 Great Britain.)

A number of photographs are reproduced showing resemblances between cell formations in the laboratory and cloud formations in the sky. The analogy is now generally accepted as based on the possible modes of instability of a top-heavy layer, but the discussion indicated a considerable diversity of opinion on details. The condensed vapour of clouds acts as an imperfect indicator since the condensed vapour may not fill the whole field of motion.

Applications to gliding are of aeronautical interest and gliding pilots will look to meteorology for information as to these convection currents and will in turn supply valuable meteorological data.

Sir George Cayley's Note-Book, Edited by J. E. Hodgson. (J.R. Aer. Soc., Vol. 37, No. 270, June, 1933, pp. 547-568.) (17.50/27132 Great Britain.)

This is an historical document of first rate importance. Systematic observations of bird flight led to a belief in the possibility of human flight and thence to investigations with a whirling arm, with flapping wings and with gliders. The author was the first to state the proportionality of lift to incidence and carried out experiments at small angles of incidence which give an approximately linear relation with lift.

Outside aerodynamical subjects the most interesting item is the development of a wheel with spokes in tension attached to a central hub. The author adds, "These wheels were patented by Jones just as Mr. Donkin and I were engaged in preparing to do so."

Numerous original sketches are reproduced in illustration of the author's versatile activity.

Meteorology and Physiology

Effect of Gusts on High Structures. (E. Rausch, Z.V.D.I., Vol. 77, No. 17, 29/4/33, pp. 433-436.) (19.10/27133 Germany.)

Various representations of assumed variation in wind velocity are given graphically. The natural period of the structure is introduced and numerical values of a dynamical stress coefficient are tabulated for different values of these variables. The principal numerical result is that gusts may increase the stresses due to wind by 100 per cent. over those produced by a steady wind.

Physiological Limitations of Flying. (G. S. Marshall, J.R. Aer. Soc., Vol. 37, No. 269, May, 1933, pp. 389-410.) (19.2/27134 Great Britain.)

The effects of altitude and rate of climb are considered in physical and physiological respects, primarily due to lack of oxygen. The necessary distinction is made between high speeds and high acceleration in considering the hydrostatic effects of the latter on blood pressures. The discussion ranged to possible heights of 50,000 feet and to accelerations of five or six times gravity. Numerous individual experiences are cited.

Two references.

Catapults

Heinkel Catapult. (Z.F.M., Vol. 24, No. 9, 13/5/33, pp. 264-265.) (20.14/27135 Germany.)

A manufacturer's specification is given of the Heinkel catapult as fitted to the s.s. Westfalen, the base ship for the South Atlantic Service of the Luft Hansa.

Three photographs show the bows of the steamer, the catapult carrying an aeroplane and details of the compressed air drive. A flying boat of 14 tons can be accelerated at 3.5 g. up to 150 km./hrs.

Aerodynamics and Hydrodynamics

Direct Determination of Velocity Field and pressure distribution on a Given Rudder Section. (F. Weinig, Werft-Reederei-Hafen, Vol. 14, No. 9, 1/5/33, pp. 117-118.) (22.0/27136 Germany.)

The problem is stated in two-dimensional form, and the methods of complex algebra are used. A distribution of sources is sought which will make the profile a streamline.

A method of graphical integration is indicated. The results of a numerical example are shown graphically for 0°, 5°, 10°, 15° incidence and resemble typical pressure distributions over a wing profile.

The moments are not evaluated, but the shift of the centre of pressure is of little importance in relation to the length of a ship.

Excitation of Waves in a Channel by a Moving End Boundary. (T. M. Burgers, Z.A.M.M., Vol. 13, No. 2, April, 1933, pp. 67-71.) (22.0/27137 Germany.)

A velocity potential function is defined by linear differential equations involving x, y and t. Periodic expressions in time and space are found, each of

which satisfies the equation of continuity, and a solution is built up satisfying the variable and fixed boundary conditions.

Experimental work indicates certain restrictions as to periodicity in time and space, but no general confirmation was obtained of the general applicability of the method to numerical predeterminations.

Ocean Currents Produced by Evaporation and Precipitation. (G. R. Goldsbrough, Proc. Roy. Soc., Vol. 141, No. A.845, 1/9/33, pp. 512-517.) (22.10/27138 Great Britain.)

When evaporation and precipitation are functions of latitude only, they cannot produce steady ocean currents. When they are functions of longitude, *e.g.*, as determined by meridianal coast lines, a definite field of velocity can be set up.

The equations of motion are solved and the stream lines plotted for an ocean roughly representing the Atlantic north of the equator. The observed precipitation is quite inadequate to account for the observed ocean currents.

Rounding and Sharpening of Edges in Stream Boundaries. (F. Weinig, Z.A.M.M., Vol. 13, No. 3, June, 1933, pp. 224-235.) (22.10/27139 Germany.)

The methods of conformal transformation are applied to obtaining boundaries with sharp corners, in two-dimensional flow.

Seven references.

Super-Critical Decompression of Compressible Fluids. (W. Schiller, F.G.I., Vol. 4, No. 3, May-June, 1933, pp. 128-137.) (22.10/27140 Germany.)

The equation of St. Vénant is quoted and the critical value of the expansion ratio is found in terms of the exponent in the equation of adiabatic expansion. Applications are made to the results of the German researches on steam nozzles, and the total flow is plotted against the pressure ratio in a series of characteristic nozzle delivery curves. German standard nozzles show the expected constant delivery for all velocities above the critical value, but diaphragms show increasing flow up to zero ratio of expansion.

Twenty-five references.

Resistance of a Cylinder Due to Normal and Tangential Stress Distribution. (L. Schiller and W. Linke, Z.F.M., Vol. 24, No. 7, 13/4/33, pp. 193-198.) (22.10/27141 Germany.)

The separation of the partial resistance by direct measurement is difficult owing to the relatively small contribution of the tangential stresses at moderately high Reynolds numbers. Favourable reference is made to A. Thom's solution of the equations of motion in the boundary layer.

The tangential forces are calculated up to the branching points at which the stream, initially following the surface, is diverted therefrom and an empirical expression is formed for the relatively small contribution of the tangential stresses in the unstable sector beyond the branching points. The semi-empirical expression is shown to be in substantial agreement with careful measurements over a range of Reynolds numbers for 5,000 to 40,000.

Measurement of Apparent Mass of Ship Models. (C. von den Steinen, Werft-Reederei-Hafen, Vol. 14, No. 7, 1/4/33, pp. 89-91.) (22.10/27142 Germany.)

The rate of acceleration of the model is measured by a pen vibrating with constant period 1/100 sec., transverse to a record strip moving with the model. The arrangement is shown in sketches and a record is reproduced with calibration. The acceleration curve is drawn and the additional mass acceleration is

found as the difference between the applied force and the model's mass acceleration.

Empirical expressions are fitted to the experimental results.

Dynamics of Ship's Motion in Seaway. (W. Späth, Werft-Reederei-Hafen, Vol. 14, No. 8, 15/4/33, pp. 104-106.) (22.10/27143 Germany.)

A study of rolling is based on vector diagrams giving point to point values of the resultant rolling couple produced by the restoring couple, moment of inertia, and friction.

Values of the resultant couple are shown graphically as functions of the angle of roll; for different frequencies of the impressed forces the maximum rolling angle is shown as a function of the ratio of natural period to frequencies of impressed forces.

Influence of Viscosity of Water on Turbine Performance. (Roe, Z.V.D.I., Vol. 77, No. 13, 1/4/33, p. 355.) (22.10/27144 Germany.)

Performance tests were carried out at water temperatures from 1°C. to 70°C. For fixed blade setting and constant r.p.m. the efficiency increased with increasing temperature in a nearly linear relation. The maximum improvement was +3 per cent. efficiency with a concomitant increase of 0.3 per cent. in the quantity of water per second.

Potential Flow Round a Biplane. (E. Pistolesi, L'Aerotecnica, Vol. 13, No. 3, March, 1933, pp. 185-193.) (22.10/27145 Italy.)

Following Millikan, general transformations are simplified by placing a concentrated vortex at the centre of vorticity along with a doublet of appropriate strength and direction. The resulting analysis is shortened and simplified in the present paper.

Research on Mechanics of Fluids. (P. Léglise, L'Aéron., No. 169, June, 1933, pp. 136-138.) (22.15/27146 France.)

A review is given of research work carried out by Martinot-Lagarde and Guillemet on visual observation of fluid motion. Numerous photographic records are reproduced of fluid motion in a wind channel rendered visible by filaments of hot air, and illustrating flow past a wing below and above stalling incidence and flow past a cylinder; and of flow of relatively highly viscous oils with free surface past cylinders rendered visible by powdered aluminium on the surface. The latter are particularly rich in detail and show the progressive differences with Reynolds numbers from 9 to 360.

Fluids in Turbulent Motion. (A. Fage, J.R. Aer. Soc., Vol. 37, No. 271, July, 1933, pp. 573-600.) (22.15/27148 Great Britain.)

The paper describes visual observations by microscope of motions of minute mineral particles contained in ordinary tap water which, by reason of their small size, do not disturb sensibly the flow which carries them along. Unfortunately, a square or slightly rectangular section is imposed by the requirements of microscopic observation, and this introduces complications avoidable only by using a circular section or a long, narrow rectangular section.

Nevertheless, an important body of experimental observations on the velocity field is presented. As a contribution to the interpretation thereof the writer gives a useful summary of the attempts made to resolve the formidable difficulties presented by the differential equation of viscous fluid motion. From his quoting of Reynolds' remarks on the need for visual observation and his own experimental contributions, it may be inferred that he is of Reynolds' persuasion. A discussion

followed to which Professor Taylor and Professor Prandtl contribute. The subject is too extensive and the interpretation of the results too obscure for concise abstracting, but the methods and results described will influence deeply subsequent investigations.

Experimental Investigation of the Generation of Turbulence. (J. Nikuradse, Z.A.M.M., Vol. 13, No. 3, June, 1933, pp. 174-176.) (22.15/27149 Germany.)

For comparison with Schlichting's results (see Abstract 27160) experiments were carried out in a water channel. A description is given of the channel and of elaborate devices for maintaining steady flow and for introducing disturbances of prescribed frequencies.

The experimental points at which the disturbance increases are plotted, along with Schlichting's boundary curve of neutral equilibrium, and lie on a narrow vertical belt which is bounded by the lower branch of the neutral curve but extends far beyond the upper branch. The interpretation is not immediately obvious.

The critical value without artificial disturbance is $R=655{,}000$.

Four references.

Dynamical View of Turbulence. (F. Noetner, Z.A.M.M., Vol. 13, No. 2, April, 1933, pp. 115-120.) (22.15/27150 Germany.)

The distribution of velocity across a two-dimensional flow is represented approximately by the field velocity due to superposition of Karman rows of vortex pairs.

A condition of minimum instability is sought by the usual methods, and leads to a number of conditions analogous to those found in the simple case of one double row. It appears that any such arrangement is unstable for a perfect fluid.

Nine references.

The Mean Square Value of Axial Oscillations in Turbulent Flow in a Pipe. (H. Reichardt, Z.A.M.M., Vol. 13, No. 3, June, 1933, pp. 177-180.) (22.15/27151 Germany.)

A hot wire instrument was used, the length of the wire being kept down to 2 mm. to localise the effects in space, the diameter being 0.007 mm. The small variations in potential drop were increased 10^5 times by a direct current amplifier. A sensitive deadbeat electrodynamometer measured the mean square of the current variations, a galvanometer needle, maintained at zero deflection, indicating the maintenance of zero mean direct current.

The electromagnetic and thermal characteristics are discussed and expressions are obtained for electric current and velocity relations. The numerical results are shown graphically and in tables. The root mean square values approximately fall off inversely as the square root of distance from the walls.

Three references.

Calculation of Katzmayr Effect. (A. Lafay, Pub. Sc. et Tech., No. 24, 1933, pp. 1-16.) (22.15/27152 France.)

Periodic variation of incidence is imposed, and the time mean coefficients are expressed as integrals taken over a complete cycle. The results show general agreement with measurements.

Autorotation.—The case where the axis of rotation is parallel to the wind is immediately explained by elementary airscrew theory. Autorotation of a lamina about an axis parallel to its length and to the wind involves a variable angle of incidence passing from 0° to 360° in each cycle. The characteristics of the section of the lamina being known experimentally, the existence of a time-mean couple is readily deduced by graphical or numerical methods.

Stability of a Local Vortex Moving Round a Corner. (A. Miyadzu, Phil. Mag., Vol. 16, No. 106, Sept., 1933, pp. 553-562.) (22.15/27153 Great Britain.)

Methods of conformal transformation are used to derive the flow potential near an angle from the potential flow near an infinite plane. The vortex is found to be in neutral equilibrium on a line bisecting the angle when a certain relation exists between the intensity of the vortex and the velocity parameter of the main flow.

Only a summary is given of the analysis, but a comprehensive graphical representation makes clear the general nature of the solutions.

Motion of an Eddy Round the End of a Barrier. (G. Hamel, Z.A.M.M., Vol. 13, No. 2, April, 1933, pp. 98-101.) (22.15/27154 Germany.)

Methods of conformal representation are applied and a velocity potential variable in time is defined by a linear differential equation.

The solution is found and applied to determine the paths of an eddy round a plane barrier and through a gap in a plane. Infinite velocity at an edge can be avoided in the latter case by superposition of eddies at the edges of the gap, but in the former case the potential function and the pressure become many valued and the solution must be rejected.

Two references.

Flow Past Circular Cylinders at Low Speeds. (A. Thom, Proc. Roy. Soc., Vol. 141, No. A.845, 1/9/33, pp. 651-669.) (22.15/27155 Great Britain.)

A method of numerical solution of the equations of two-dimensional viscous steady flow was developed in a previous paper. The field is ruled into squares. Initial values of steam function and vorticity are assumed at the corner, and the resultant values at the centres are found by interpolation and so on. If the initial assumptions are sufficiently near the true values and the squares are small enough, the results are true solutions.

The stream function and vorticity iso-curves are plotted graphically on an intermediate t-plane. The stream lines are finally plotted in the w-plane and exhibit two symmetrical stationary vortices behind the cylinder. The similarity of the calculated field at Reynolds number 20, with the experimental field at $R=29$, shows that the approximations bring out the observed phenomena. At higher speeds instability sets in.

Nine references.

Fall of a Strip of Paper. (J. G. Baker, Phil. Mag., Vol. 16, No. 103, July, 1933, pp. 175-178.) (22.15/27156 Great Britain.)

Experiments were made with autorotation of a pivoted strip in an air current and with a falling strip. A qualitative description of the variation of the turbulent wake is outlined, as an explanation of the general nature of the phenomenon.

Experimental Study of Vortex Rings at Low Velocities. (C. Sadron, Pub. Sc. et Tech., No. 22, 1933.) (22.15/27157 France.)

A descriptive account is given of the formation and propagation of vortex rings, with photographs and numerical results, with a brief discussion of different suggestions as to the qualitative mechanism. The author's experimental apparatus is described and photographs are reproduced. No mathematical physical interpretation is attempted.

Eleven references.

Instability of Liquid Jets. (E. Tyler, Phil. Mag., Vol. 16, No. 105, Aug., 1933, pp. 504-518.) (22.2/27158 Great Britain.)

Experimental determinations of the wave-length of drop formations were carried out by spark photographs, by photo-electric records, and by stroboscopic

methods. Thirty-four photographs are reproduced and show considerable irregularities.

Numerical results are given in tables according to the method employed, and the mean values are in substantial agreement with Rayleigh's theory. The arrangement of the apparatus in the three methods is of general interest.

Thirteen references.

Effect of Jets of Air Emitted Parallel to the Surface of Bodies. (A. Lafay, Pub. Sc. et Tech., No. 24, 1933, p. 31.) (22.3/27159 France.)

The method is applied to circular cylinders and to wing profiles. Four polar characteristics of wings are reproduced and show the improvement thus obtained, particularly for incidence above normal stalling values.

Calculation of Time Increments of Small Disturbances in Laminar Flow Along a Plate. (H. Schlichting, Z.A.M.M., Vol. 13, No. 3, June, 1933, pp. 172-174.) (22.3/27160 Germany.)

By an extension of Tollmien's work on critical instability, time increments of small disturbances are calculated, neglecting squares of increments, for different values of Reynolds numbers, R = max. velocity × depth of boundary layer/kinematic viscosity.

A family of iso-increment curves is obtained with Reynolds numbers and reciprocals of wave-lengths as co-ordinates, all as non-dimensional parameters. The curves are closed on the left-hand side of the diagram, and the limiting curve of zero increment separating the stable and unstable regions of the diagram, corresponds to Tollmien's solution.

In the generalised solution a disturbance of given frequency, carried downstream along the plate, first passes through a region of stability and then enters a region of instability, the total increment being obtained by integration with respect to time.

Numerical results are shown graphically and give stability below $R \cong 10^5$

The experimental limits of stability found by Burgers and Hansen and by Blasius and Gebers are at values $R = 2.5 \times 10^5$ and $R = 5 \times 10^5$ respectively, with time increments of 4 and 9 for the most sensitive disturbance according to the results of the present paper.

Ten references.

Sucking Away the Boundary Layer. (O. Schrenk, Z.A.M.M., Vol. 13, No. 3, June, 1933, pp. 180-182.) (22.3/27161 Germany.)

It is pointed out that the orifice acts as a sink and sets up velocity and pressure fields which are superposed on the undisturbed field. Prandtl's explanation is restricted to the removal of the ultimately unstable boundary layer fluid, which would in itself be sufficient to maintain steady flow. The writer considers that experimental measurements show a stabilising effect of the superposed pressure field when the boundary layer is not completely removed.

Skin Friction of Flat Plates. (N. A. V. Piercy and H. F. Winny, Proc. Roy. Soc., Vol. 140, No. A.842, 1/6/33, pp. 547-561.) (22.3/27162 Great Britain.)

The approximate equation of slow viscous motion in Oseen's form was solved by Bairstow in the form of an integral equation as a distribution of doublets along the plate.

In the present paper the core is expanded in series and first and second approximations are discussed and an asymptotic solution is obtained in a simple form. Fields of velocity and vorticity are shown graphically.

The results are compared graphically with the solution given by Blasius and with Hansen's experimental values.

Resistance of Impact of a Cone on a Water Surface. (S. Watanabe, Inst. of Phys. and Chem. Research, Tokyo, Scientific Paper No. 268, 20/9/30, pp. 153-168. See Phys. Zeit., No. 12, 15/6/33, pp. 494-495.) (22.35/27163 Japan.)

The piezo-electric effect of pressure on a quartz plate was recorded by a cathode ray oscillograph. A number of oscillograms show the rise of pressure to a maximum followed by a fall to a steady value. Elementary approximate expressions for impact are constructed and confirm the general run of the experiments. Interesting relations between maximum, height of fall, cone angle and position of maximum instantaneous pressure are established.

Materials—Elasticity and Plasticity

Forced Oscillation of Two Systems with Friction Coupling. (E. Hahnkamm, Z.A.M.M., Vol. 13, No. 3, June, 1933, pp. 183-202.) (23.0/27164 Germany.)

Linear differential equations are formed and solved in the usual way. Resonance and phase changes are discussed, numerical results are shown graphically for a variety of conditions. Two numerical examples are worked out in application to the Anschütz gyroscopic compass and the artificial gyroscopic horizon. An apparatus was made up, to check the theory, in the form of a fluid pendulum coupled to a spiral spring. The numerical data are given and the characteristics determined experimentally. Rules are given for selection of the most suitable characteristics.

Seven references.

Oscillation in Buildings. (G. Scharrer and O. Brötz, Forschungsheft, No. 359, March-April, 1933.) (23.0/27165 Germany.)

Vibration of ceiling and walls of rooms was investigated under conditions of resonance, and a simplified mathematical expression was formed from which it is possible to predict response to impulses of known frequency. A mathematical investigation of the longitudinal and transverse vibration of brick pillars is attempted.

Thirty-nine references.

Working Charts for the Stress Analysis of Elliptic Rings. (W. F. Burke, N.A.C.A. Tech. Note No. 444.) (23.10/27166 U.S.A.)

Reference is made to a paper by A. R. Miller on stresses in circular frame rings for monocoque aeroplane bodies. The work is extended in the present paper to elliptic rings of uniform cross-section under steady concentrated loads symmetrical about the major axis. Elementary linear relations are written down between loading and stresses and moment with coefficients which are functions of the eccentric angle. Graphical charts give numerical values of the coefficients in terms of the eccentric angle and of the latter in terms of the angular position.

Three numerical examples are worked out. The calculations, making use of the minimum energy principle, involve elliptic integrals and are not reproduced as they are not new.

Creep Phenomena—a New Group of Problems of Technical Importance in the Theory of Elasticity. (A. Stodola, Z.A.M.M., Vol. 13, No. 2, April, 1933, pp. 143-146.) (23.10/27167 Germany.)

Reference is made to data given by R. W. Bailey (in a paper read at the Tokyo World Power Conference, 1929, and reproduced in *Engineering*, February,

1930, pp. 265, etc.). In the creep phenomena there is no limiting state of equilibrium, and the time variable does not ultimately disappear from the differential equations, as in the equations of plastic-elastic strain. This fact gives novelty, interest and importance to the new group of problems.

Elementary cases of bent beams are discussed and the solution is made to depend on graphic integrations, of which numerical examples are given.

One reference.

Buckling Load of Rectangular Plate with Four Clamped Edges. (G. I. Taylor, Z.A.M.M., Vol. 13, No. 2, April, 1933, pp. 147-152.) (23.10/27168 Germany.)

The problem has been solved for other boundary conditions which lead to comparatively simple solutions, since the displacement is a simple harmonic function of one of the co-ordinates. With all four edges clamped, this type of displacement is not possible and no previous complete solution has been offered.

In the present paper the solution is made to depend on an infinite determinant. The numerical values of the roots of successive minors, about the diagonal, of increasing order, were found by slide rule work and converge to a final value taken as 5.30. Values of 5.61 and 5.33 were found by Sezawa and Ritz by approximate methods, but the close agreement of the latter is considered to be probably fortuitous.

Four references.

Photo-Elastic Effect in Phenolite. (J. Kuno, Phil. Mag., Vol. 16, No. 105, Aug., 1933, pp. 353-362.) (23.15/27169 Great Britain.)

The characteristics of the material were investigated, taking into account heat treatment, temperature and duration. Numerical values of Young's modulus and the coefficient of extinction are tabulated for five materials. Empirical time relations suggested by Filon and Jessop are quoted. It is considered that the optical effect is more directly connected with strain than with stress.

Seven references.

Thin Tubes Under Combined Stresses. (C. P. Casiraghi, L'Aerotecnica, Vol. 13, No. 6, June, 1933, pp. 757-766.) (23.30/27170 Italy.)

Results of American experimental data are expressed in simple forms suitable for calculation, with a semi-empirical coefficient determined from a graphical chart.

Five references.

Strains and Stresses in a Thin Cylindrical Sheet Lying Freely on its Edges and Loaded Arbitrarily. (H. Reissner, Z.A.M.M., Vol. 13, No. 2, April, 1933, pp. 133-138.) (23.41/27171 Germany.)

Navier's method of integration is extended and more general boundary conditions are considered than those previously introduced by v. Mises.

Appropriate solutions of the differential equations of elasticity are developed in series and the expressions employed are tabulated numerically and applied to numerical examples.

Three references.

Torsional Stability of Monocoque Fuselage. (K. Sezawa, J.R. Aer. Soc., Vol. 37, No. 269, May, 1933, pp. 411-422.) (23.41/27172 Great Britain.)

The elastic equations for a cylinder are quoted and simplified for thin walls. Solutions are assumed as simple sine functions of axial and angular co-ordinates, and the resulting determinantal equation of compatibility is solved for an assumed

value of Poisson's ratio, one half, and for particular numerical values of the parameter involved. The results are tabulated and plotted and minimum critical values are derived.

An experimental mounting is described and two photographs show the cylinders in torsional strain with spiral corrugations.

Experimental values are compared with calculation values and show considerable disagreement, particularly in the number of nodes. None the less, they are held to confirm the mathematical method in principle, and divergences are explained by details in the mounting.

Miscellaneous

Form and Structure of Lead Shot. (G. Tammann and K. L. Dreyer, Z. Metallk., Vol. 25, No. 3, March, 1933, p. 64.) (27173 Germany.)

Arsenic or antimony is added to the melt to obtain accurately spherical shot. These substances react with lead oxide and form a film of arsenide or antimonide which remains liquid at relatively low temperatures. Possible change in the surface tension is not an effective factor.

Short Circuit Arcs. (W. Ende, Ann. d. Phys., Vol. 17, No. 4, June, 1933, pp. 460-464.) (27174 Germany.)

Three cinematograph records show the rupture of a silver conducting wire with formation of the arc.

After the brief duration of the arc, roughly 1/1,000 sec., the records show the wire collapsing into small spherical globules, groups of which may unite to form larger globules. The rate was from 3,100 to 6,730 exposures per second.

PART II.—AIRCRAFT AND ENGINES : PERFORMANCE

Dornier Do.Y Freight Machine (and Heavy-Load Carrier). (Flugsport, Nov. 8th, 1933, No. 23.) (4.44/47 Germany.)

The "Do.Y," constructed by the "A.G. fur Dornier-Flugzeuge," Altenrhein (Switzerland), is a cantilever high-wing machine.

The three-spar wing is fabric-covered, except near the engine where it is covered with sheet-metal. The fuselage is covered with duralumin.

Three air-cooled Bristol-Jupiter VI engines without gearing are fitted, two in the leading edge of the wing on either side of the fuselage, the third on an engine bracket above the wing.

Span.—92 ft.
Length.—60 ft.
Height (with stationary airscrews).—20 ft.
Wing area.—1,196 sq. ft.
Engine power.—3 × 350/500 h.p. Bristol-Jupiter VI engines.
Fuel capacity.—3,539 lbs. in wing tanks.
Oil capacity.—403 lbs. in tanks in leading edge of wing for the two lateral engines, and in tank in engine nacelle for the central engine.
Weight equipped.—11,000 lbs.
Useful load.—7,700 lbs.
Total loaded weight.—18,700 lbs.
Wing loading.—15.65 lb./sq. ft.
Power loading.—11.9 lbs./h.p.
Maximum speed.—161.6 m.p.h.
Cruising speed.—136.7 m.p.h.
Landing speed.—55.9 m.p.h.
Ceiling.—19,500 ft.
Range.—931 miles.

Stipa "Flying Tube." (L'Ala d'Italia, October, 1933.) (4.68/11 Italy.)

The fuselage is of hollow tubular form.

Total loaded weight.—1,870 lbs.
Wing area.—205 sq. ft.
Wing loading.—9 lbs./sq. ft.

Performance:—

Maximum speed.—82.66 m.p.h.
Minimum speed.—42.2 m.p.h.
Time of climb to 10,000 ft.—40 mins.
Landing and taking-off run, without wheel brakes.—590 ft.

The Dewoitine D.332. (Interavia, No. 41, 24/8/33.) (4.37/46 France.)

Three "9 V" Hispano-Suiza engines (575 h.p.) air-cooled, with true N.A.C.A. cowlings; two-blade all-metal Levasseur airscrews; emitting and receiving wireless equipment; the three fuel tanks with a total capacity of 704.3 imp. gals.

Span.—95.15 ft.
Length.—62.15 ft.
Height.—17.88 ft.
Wing area.—1,033 sq. ft.
Gross weight.—20,513 lbs.
Useful load.—8,973 lbs. (of which 4,850 lbs. is fuel).
Maximum speed.—186.4 m.p.h.
Cruising speed.—155.3 m.p.h.
Ceiling (with two engines running).—9,843 ft.
Range.—1,245 miles.
Crew.—Two pilots and assistant.

The World Record F.I.A.T. Macchi M.C. 72. (Luftwacht, No. 4, April, 1933, pp. 140-141.) (4.67/12 Italy.)

In its general form the Macchi resembles the British Supermarine which was the previous record holder.

The construction is mainly in duralumin, and wing and float surfaces are used to cool water and oil. The engine consists of two independent 12-cylinder V's of 25 litres stroke volume each. A reduction gear between the engines operates two tandem airscrews rotating in opposite direction. The engines are stated to give a total of 2,800 h.p. at 3,200 r.p.m. for a weight of 920 kg. (2,024 lbs.).

Jumo Two-Stroke Diesel Engine for Aircraft, Series 5. (Automotive Industries, 2/9/33, p. 280.) (3.43/1 Germany.)

Characteristics.—Bore 105 mm., stroke 2 × 160 mm., six cylinders, 420/540 h.p. at 2,100 r.p.m.; dry weight 2,000 lbs., including vibration damper and fuel pump.

The German Airworthiness Certificate has been obtained.

TAPERED FRAMEWORKS REPRESENTATIVE OF THE AIRSHIP HULL

BY

L. CHITTY, A.F.R.AE.S.

1. In recent years a systematic research has been made into the methods available for determining the stresses in three dimensional braced frameworks, and in particular into frameworks of the type represented by the hull of a rigid airship. Much of the research has been of a generalised character, intended to act as a useful guide to the designer rather than to deal with any particular problem of loading with which he may be confronted; attention has therefore been largely (though not entirely) concentrated on the stresses in a fully braced parallel tubular structure such as is shown in Fig. 1, in which the wire bracing

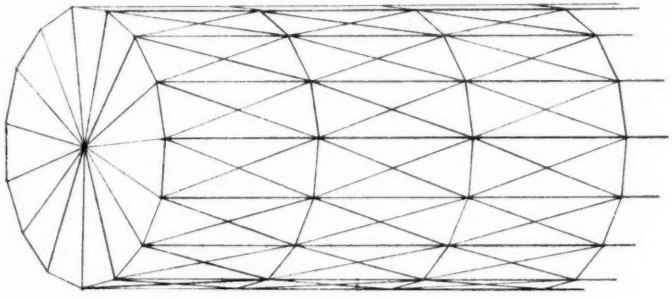

FIG. 1.

or " tension " members are initially strained so as to be capable of carrying compression,—the slackening off of wires, which will of course take place before failure, being considered subsequently by the " device of the separate panel."

On the practical side special reference is needed to a series of tests which were carried out by Prof. A. J. S. Pippard and Mr. J. F. Baker on a parallel tubular framework consisting of three bays of regular hexagonal cross-section.[1]

A complete review of the progress made up to 1926 on the theoretical side was given in the R.38 Memorial Essay for that year.[2] Special reference is needed here to a series of papers on the stresses in tubular frameworks,[3] which formed part of the basis for the Report of the Airship Stressing Panel.[4]

A description of a new theoretical line of attack upon the stresses in the parallel tubular structure—by a method akin to Fourier analysis—was given in one of the Memorial Essays for 1931.[5] In all these theoretical researches certain definitely limiting assumptions were made, either (*a*) as to the distribution of the

[1] R.Ae.S. Journal, May, 1926, " Experimental Stress Analysis of Frameworks with Special Reference to Problems of Airship Design," by A. J. S. Pippard. See also R. & M. 948, 971 and 977.

[2] R.Ae.S. Journal, November, 1926, " Stresses in Rigid Airships," by R. V. Southwell.

[3] R. & M. 737, 790, 791 and 819, " On the Determination of the Stresses in Braced Frameworks," by R. V. Southwell.

[4] R. & M. 800.

[5] R.Ae.S. Journal, December, 1931, " A Contribution to the Analysis of Primary Stresses in the Hull of a Rigid Airship," by L. Chitty and R. V. Southwell.

applied loads among the joints of the bulkheads, or (*b*) as to the rigidity of those members which form the bulkheads in the structure.

2. In a recent paper to the Royal Society,[6] Prof. R. V. Southwell has outlined a method (an extension of the method described in 1931) by which the stresses in a fully braced parallel tubular structure, consisting of any number of identical bays, can be obtained when either the displacements or the forces at the joints of the terminal bulkheads are specified in any arbitrary manner, and this method is free from assumptions as to the rigidity of the bulkhead members. The method consists in analysing the given terminal conditions into a series of " type systems " in each of which the displacements of the joints throughout the structure have definite values depending in a particular manner on the geometric and elastic properties of the members. These " type systems " are first constructed and their amplitudes evaluated, then the displacements of the joints under the actual conditions are obtained by synthesis. The stresses in the members can then be determined.

In R. & M. 1528[7] I applied this method to the hexagonal tubular framework described in R. & M. 948 experiment No. 4;[8] thus obtaining a comparison between the measured and theoretical stresses in the members. In the example chosen a system of radial bracing was present in each bulkhead in the structure; the modification of the method to deal with cases where the intermediate bulkheads are left unbraced is being carried out by Mr. J. B. Owen at Oxford (T. 3407*b*).

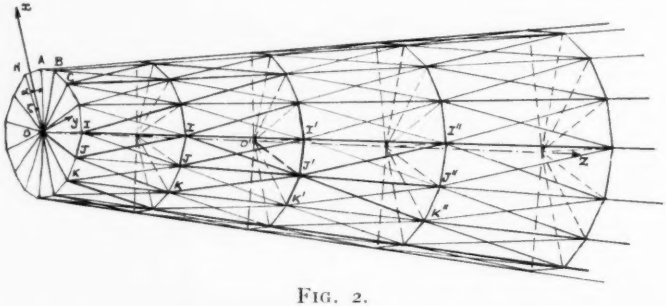

FIG. 2.

As has been stated, most of the research has been made on a parallel tubular structure, but the treatment of an isolated tapered bay was given in R. & M. 819;[9] this treatment was subject to limitations of the kind (*a*) already mentioned. The present paper shows, however, that the analysis of Prof. Southwell's recent paper can readily be extended to certain classes of tapered tubes.

In the analysis of the parallel tube it was assumed that all members of the same type were identical in length and in elastic properties. Here it is assumed that in any one bay or bulkhead members of the same type are identical in length and elastic properties, that the taper is straight, and that the bays are geometrically similar, while the elastic properties of the members also vary from bay to bay according to a geometric law.[10] On these assumptions the structure forms a right regular polygonal cone the apex of which is virtually excluded.

[6] Proc. Roy. Soc. A, Vol. 139, 1933, " On the Calculation of Stresses in Braced Frameworks," by R. V. Southwell, F.R.S.

[7] " Application of a Method for Determining the Stresses in Braced Frameworks," by L. Chitty.

[8] See footnote (1).

[9] See footnote (3).

[10] Somewhat similar assumptions are made by Dr. H. Ebner in a valuable paper relating to frameworks of rectangular cross-section: 235. Bericht der D.V.L., " Die Berechnung regelmässiger, vielfach statisch unbestimmter Raumfachwerke mit Hilfe von Differenzengleichungen," by H. Ebner.

The analysis is therefore confined to a truncated cone as shown in Fig. 2, in which either displacements or forces (but not a mixture of both at one end) are specified at the joints of either terminal bulkhead.

The parallel tube with identical bays is thus a very particular case of the present analysis; it is, however, a case involving certain particular forms for the "type systems" (see §20, case (6)) which cannot be deduced directly by putting the taper zero and the elastic properties constant in the formulæ for the tapered tube. The more general assumptions made here in regard to the elastic properties can be readily extended to the parallel tube.

Notation

3. It is assumed that the bulkheads are of regular polygonal form and that the radial members in the terminal bulkheads, and similarly (if present) those in the intermediate bulkheads, meet in a central joint O, so that the angle between adjacent radial members is

$$\alpha = 2\pi/N, \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where N is the number of sides in the polygon.

The axis of z is taken along the axis of the tube and a convenient datum line Ox is chosen in the plane of one of the bulkheads and Oy taken perpendicular to it. Starting in a clockwise direction from the datum line (when looking in the direction of positive z), the joints round a bulkhead are lettered

$$A, \quad B, \quad C, \ldots, \quad I, \quad \mathbf{J}, \quad K, \ldots, \quad N,$$

or numbered

$$1, \quad 2, \quad 3, \ldots, \quad j-1, \quad j, \quad j+1, \ldots, \quad N,$$

and their angular position is given by

$$\alpha-\zeta, \ 2\alpha-\zeta, \ 3\alpha-\zeta, \ \ldots, \ (j-1)\,\alpha-\zeta, \ j\alpha-\zeta, \ (j+1)\,\alpha-\zeta, \ \ldots, \ N\alpha-\zeta,$$

where ζ is the angle NOx.

In what follows, for brevity, ζ is taken as zero, *i.e.*, it is assumed that the datum line passes through the joint N; if this is not the case, the angle $(j\alpha-\zeta)$ must be substituted for the angle $j\alpha$ *except when* $j\alpha$ *is associated with* $n=\frac{1}{2}N$ (see §18).

The apex of the cone (produced) is lettered P.

4. The following scheme is used to denote the lengths of the various members:—

Bulkhead No.	...	0,	1,	2, ...,	β,	$\beta+1$,	$\beta+2$, ...,
Radial member	...	r_0,	r_1,	r_2, ...,	r,	r',	r'', ...,
Transverse strut	...	t_0,	t_1,	t_2, ...,	t,	t',	t'', ...,
Bay No.	...	...	0,	1,	2, ...,	β,	$\beta+1$, ...,
Bay length	...	...	L_0,	L_1,	L_2, ...,	L,	L', ...,
"Longitudinal"	...	...	l_0,	l_1,	l_2, ...,	l,	l', ...,
Diagonal member	...	...	d_0,	d_1,	d_2, ...,	d,	d', ...,

where β denotes a general intermediate bulkhead and bay.

Since the taper is assumed to be straight,

$$(r_1-r_0)/L_0=(r_2-r_1)/L_1=\ldots=(r'-r)/L=(r''-r')/L'=\ldots=\tan\theta, \quad (2)$$

where θ is the angle of taper (Fig. 3).

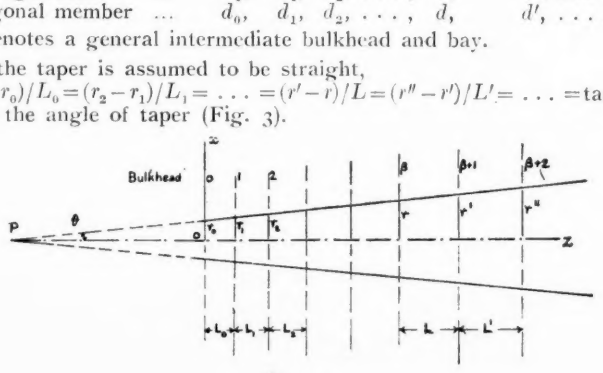

FIG. 3.

Further, if the bays are assumed to be geometrically similar,

$$L_0/r_0 = L_1/r_1 = \ldots = L/r = L'/r' = \ldots = c, \qquad (3)$$

where c is a constant which defines the " aspect ratio " of the bay.

Combining assumptions (2) and (3), it follows that a single constant a, where

$$a = 1 + c \tan \theta, \qquad (4)$$

can be used to relate the lengths of the members in any two bays or bulkheads; thus, in accordance with the scheme of notation given,

$$\left.\begin{aligned} L &= cr = cr_0 a^\beta, \\ L' &= cr' = cr_0 a^{\beta+1}. \end{aligned}\right\} \qquad (5)$$

The actual lengths of the members in the βth bulkhead or bay are

$$\left.\begin{aligned} r &= r_0 a^\beta, \\ t &= t_0 a^\beta = 2r_0 a^\beta \sin \alpha/2, \\ l &= cr_0 a^\beta \sqrt{(1 + \tan^2 \theta)}, \\ d &= r_0 a^\beta \sqrt{\{ c^2 (1 + \tan^2 \theta) + 2a (1 - \cos \alpha) \}}. \end{aligned}\right\} \qquad (6)$$

5. It is further assumed that the elastic properties of the members vary from bay to bay according to a geometric law; thus, if Ω^* defines the elastic properties of a member of any one type and a suffix or dash denotes the bay or bulkhead referred to,

$$\Omega_1/\Omega_0 = \Omega_2/\Omega_1 = \ldots = \Omega'/\Omega = \Omega''/\Omega' = \ldots = f^2, \qquad (7)$$

where f is a constant (the square is inserted for convenience to avoid the use of square roots later on).

In particular, if Ω_{r_0}, Ω_{t_0}, Ω_{l_0}, Ω_{d_0} define the elastic properties of the members in the bulkhead and bay 0, then in the bulkhead and bay β they are defined by

$$\left.\begin{aligned} \Omega_r &= \Omega_{r_0} f^{2\beta}, \qquad \Omega_l = \Omega_{l_0} f^{2\beta}, \\ \Omega_t &= \Omega_{t_0} f^{2\beta}, \qquad \Omega_d = \Omega_{d_0} f^{2\beta}; \end{aligned}\right\} \qquad (8)$$

and the relative elasticities can conveniently be denoted in short by

$$k_1 = \Omega_l/2\Omega_d, \quad k_2 = \Omega_t/2\Omega_d, \quad k_3 = \Omega_r/4\Omega_d (1 - \cos \alpha)^2, \qquad (9)$$

where k_1, k_2, k_3 are constant for all values of β.

6. If J' (Fig. 2) is a typical joint in an intermediate bulkhead (at which no external forces are applied), the condition for equilibrium of the joint J' can be expressed directly in terms of the tension coefficients of the nine members meeting in J': equilibrium in the radial direction is given by

$$\begin{aligned} 0 = {} & r' T_{O'J'} - (r'' - r') T_{J'J''} + (r' - r) T_{J'J} + r' (1 - \cos \alpha) (T_{J'K'} + T_{J'I'}) \\ & - (r'' \cos \alpha - r') (T_{J'K''} + T_{J'I''}) - (r \cos \alpha - r') (T_{J'K} + T_{J'I}); \end{aligned} \qquad (10)$$

equilibrium in the tangential direction is given by

$$0 = \sin \alpha \{ r'' (T_{J'K''} - T_{J'I''}) + r' (T_{J'K'} - T_{J'I'}) + r (T_{J'K} - T_{J'I}) \}; \qquad (11)$$

equilibrium in the longitudinal direction Oz is given by

$$0 = L' (T_{J'K''} + T_{J'J''} + T_{J'I''}) - L (T_{J'K} + T_{J'J} + T_{J'I}). \qquad (12)$$

On combining (10) and (12), in virtue of (2),

$$0 = r' T_{O'J'}/(1 - \cos \alpha) + r'' (T_{J'K''} + T_{J'I''}) + r' (T_{J'K'} + T_{J'I'}) + r (T_{J'K} + T_{J'I}). \qquad (13)$$

Equations (13), (11) and (12) may be regarded as the three conditions for the equilibrium of the joint J'.

The conditions for the equilibrium of the central joint O' are

$$0 = \Sigma_j [T_{O'J'} \cos j\alpha] = \Sigma_j [T_{O'J'} \sin j\alpha], \qquad (14)$$

where Σ_j denotes a summation extending to all joints in the bulkhead.

7. The displacement of any joint round a bulkhead is defined by three component displacements:—

* As a first estimate Ω = (Young's Mod. × cross-sectional area)/(length)^3; in practice allowance may have to be made for end fittings, etc.

Radial displacement u (positive direction radially outwards).
Tangential displacement v (positive direction clockwise when looking in direction of positive z).
Longitudinal displacement w (positive direction in direction of positive z).

The component displacements in any three consecutive joints in three consecutive bulkheads can then be denoted by the scheme

	β			$\beta+1$			$\beta+2$		
Bulkhead ...									
Joint	I	J	K	I'	J'	K'	I''	J''	K''
Displacement ...	u_{j-1}	u_j	u_{j+1}	u'_{j-1}	u'_j	u'_{j+1}	u''_{j-1}	u''_j	u''_{j+1}

and similar expressions for v and w.

The displacement of a central joint O' in the plane of its bulkhead is defined by two components: a' in the direction Ox and b' in the direction Oy. The displacement in the direction Oz is negligible. Thus the displacement of O' in the direction $O'J'$ is

$$u'_{OJ}=a'\cos j\alpha+b'\sin j\alpha. \quad . \quad . \quad . \quad . \quad (15)$$

8. The tension coefficients for the members in terms of the displacements u, v, w are then, in virtue of (2):—

For the typical longitudinal,

$$\begin{aligned} T_{J'J''}&=\Omega'_1L'\{(w''_j-w'_j)+(u''_j-u'_j)\tan\theta\}, \\ &=\Omega_{1o}cr_o(af^2)^{\beta+1}\{(w''_j-w'_j)+(u''_j-u'_j)\tan\theta\}, \quad . \quad . \quad . \quad (16) \end{aligned}$$

in virtue of (5) and (8);

for the typical transverse member,

$$\begin{aligned} T_{J'K''}&=\Omega'_tr'\{(1-\cos\alpha)(u'_{j+1}+u'_j)+\sin\alpha(v'_{j+1}-v'_j)\}, \\ &=\Omega_{to}r_o(af^2)^{\beta+1}\{(1-\cos\alpha)(u'_{j+1}+u'_j)+\sin\alpha(v'_{j+1}-v'_j)\}; \quad . \quad (17) \end{aligned}$$

for the typical diagonal member,

$$\begin{aligned} T_{J'K''}&=\Omega'_d[(1-\cos\alpha)(r'u''_{j+1}+r''u'_j)+\sin\alpha(r'v''_{j+1}-r''v'_j) \\ &\qquad +L'\{(w''_{j+1}-w'_j)+(u''_{j+1}-u'_j)\tan\theta\}], \\ &=\Omega_{do}r_o(af^2)^{\beta+1}[(1-\cos\alpha)(u''_{j+1}+au'_j)+\sin\alpha(r''_{j+1}-av'_j) \\ &\qquad +c\{(w''_{j+1}-w'_j)+(u''_{j+1}-u'_j)\tan\theta\}]; \quad . \quad . \quad (18) \end{aligned}$$

and for the typical radial member (if present),

$$T_{OJ'}=\Omega'_{r}r'(u'_j-u'_{OJ})=\Omega_{ro}r_o(af^2)^{\beta+1}(u'_j-u'_{OJ}). \quad . \quad . \quad . \quad . \quad (19)$$

9. Substituting these values for the tension coefficients in (13), (11) and (12), on dividing through by $r^2\Omega_d$, in virtue of (9),

$$\left.\begin{aligned} 0=\ & a^2f^2[4k_3(1-\cos\alpha)(u'_j-u'_{OJ})+2k_2\{(1-\cos\alpha)(u'_{j+1}+u'_{j-1}+2u'_j) \\ &\qquad +\sin\alpha(v'_{j+1}-v'_{j-1})\}] \\ &+(1-\cos\alpha)\{a^3f^2(u''_{j+1}+u''_{j-1})+(a^4f^2+1)2u'_j+a(u_{j+1}+u_{j-1})\} \\ &+\sin\alpha\{a^3f^2(v''_{j+1}-v''_{j-1})+a(v_{j+1}-v_{j-1})\} \\ &+c[a^3f^2\{(w''_{j+1}+w''_{j-1})+(u''_{j+1}+u''_{j-1})\tan\theta\} \\ &\qquad -(a^3f^2-1)2(w'_j+u'_j\tan\theta) \\ &\qquad -\{(w_{j+1}+w_{j-1})+(u_{j+1}+u_{j-1})\tan\theta\}], \\ 0=\ & a^2f^2 2k_2\{(1-\cos\alpha)(u'_{j+1}-u'_{j-1})+\sin\alpha(v'_{j+1}+v'_{j-1}-2v'_j)\} \\ &+(1-\cos\alpha)\{a^3f^2(u''_{j+1}-u''_{j-1})+a(u_{j+1}-u_{j-1})\} \\ &+\sin\alpha\{a^3f^2(v''_{j+1}+v''_{j-1})-(a^4f^2+1)v'_j+a(v_{j+1}+v_{j-1})\} \\ &+c[a^3f^2\{(w''_{j+1}-w''_{j-1})+(u''_{j+1}-u''_{j-1})\tan\theta\} \\ &\qquad -\{(w_{j+1}-w_{j-1})+(u_{j+1}-u_{j-1})\tan\theta\}], \\ 0=\ & 2k_1c\{a^2f^2(w''_j+u''_j\tan\theta)-(a^2f^2+1)(w'_j+u'_j\tan\theta) \\ &\qquad +(w_j+u_j\tan\theta)\} \\ &+(1-\cos\alpha)\{a^2f^2(u''_{j+1}+u''_{j-1})+(a^3f^2-1)2u'_j-a(u_{j+1}+u_{j-1})\} \\ &+\sin\alpha\{a^2f^2(v''_{j+1}-v''_{j-1})-a(v_{j+1}-v_{j-1})\} \\ &+c[a^2f^2\{(w''_{j+1}+w''_{j-1})+(u''_{j+1}+u''_{j-1})\tan\theta\} \\ &\qquad -2(a^2f^2+1)(w'_j+u'_j\tan\theta) \\ &\qquad +\{(w_{j+1}+w_{j-1})+(u_{j+1}+u_{j-1})\tan\theta\}]. \end{aligned}\right\} \quad (20)$$

Substituting also from (19) in (14),

$$0 = \Sigma_j \left[(u'_j - u'_{0J}) \cos j\alpha \right] = \Sigma_j \left[(u'_j - u'_{0J}) \sin j\alpha \right]. \quad . \quad . \quad (21)$$

10. It is convenient at this stage to introduce the notation of Proc. Roy. Soc. A, Vol. 139, p. 475ff, §13: If x is the value assumed by some quantity at a joint in the bulkhead β and x', x'', . . . , are the values assumed at the corresponding joints in the bulkheads $\beta+1$, $\beta+2$, . . . , then

$$\Delta x = x' - x$$
$$\Delta^2 x = \Delta\,(\Delta x) = (x'' - x') - (x' - x),$$

whence

$$\left.\begin{aligned} x' &= [1+\Delta]\, x, \\ x'' &= [1+\Delta]^2\, x, \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (22)$$

and so on.

Making use of a simple theorem relating to the coefficients in the binomial expansion[11] it can then be shown that the solution of any difference equation of the general form

$$0 = [1 + \Delta - p]^q\, x, \quad . \quad . \quad . \quad . \quad . \quad (22a)$$

where p is constant and q an integer, is of the form

$$x = p^\beta \{ A + B\beta + C\beta^2 + \ldots + Q\beta^{q-1} \}, \quad . \quad . \quad (22b)$$

where A, B, C, . . . , Q are constants.

In this new notation, the three equations (20) may be written in the form

$$\left.\begin{aligned}
0 &= (1-\cos\alpha) \{ [a^3 f^2 (1+\Delta)^2 + 2k_2 a^3 f^2 (1+\Delta) + a] (u_{j+1} + u_{j-1}) \\
&\qquad + 2 [1+\Delta] [(a^4 f^2 + 1 + 2k_2 a^2 f^2) u_j + 2k_3 a^2 f^2 (u_j - u_{0J})] \} \\
&\quad + \sin\alpha [a^3 f^2 (1+\Delta)^2 + 2k_2 a^2 f^2 (1+\Delta) + a] (v_{j+1} - v_{j-1}) \\
&\quad + c \{ [a^3 f^2 (1+\Delta)^2 - 1] [(w_{j+1} + w_{j-1}) + (u_{j+1} + u_{j-1}) \tan\theta] \\
&\qquad - (a^3 f^2 - 1)\, 2 [1+\Delta] (w_j + u_j \tan\theta) \}, \\
0 &= (1-\cos\alpha) [a^3 f^2 (1+\Delta)^2 + 2k_2 a^2 f^2 (1+\Delta) + a] (u_{j+1} - u_{j-1}) \\
&\quad + \sin\alpha \{ [a^3 f^2 (1+\Delta)^2 + 2k_2 a^2 f^2 (1+\Delta) + a] (v_{j+1} + v_{j-1}) \\
&\qquad - (a^4 f^2 + 1 + 2k_2 a^2 f^2)\, 2 [1+\Delta] v_j \} \\
&\quad + c [a^3 f^2 (1+\Delta)^2 - 1] [(w_{j+1} - w_{j-1}) + (u_{j+1} - u_{j-1}) \tan\theta], \\
0 &= (1-\cos\alpha) \{ [a^2 f^2 (1+\Delta)^2 - a] (u_{j+1} + u_{j-1}) + (a^3 f^2 - 1)\, 2 [1+\Delta] u_j \} \\
&\quad + \sin\alpha [a^2 f^2 (1+\Delta)^2 - a] (v_{j+1} - v_{j-1}) \\
&\quad + c \{ [a^2 f^2 (1+\Delta)^2 + 1] [(w_{j+1} + w_{j-1}) + (u_{j+1} + u_{j-1}) \tan\theta] \\
&\qquad + 2k_1 [a^2 f^2 (1+\Delta)^2 - (a^2 f^2 + 1)(1+\Delta) + 1] (w_j + u_j \tan\theta) \\
&\qquad - (a^2 f^2 + 1)\, 2 [1+\Delta] (w_j + u_j \tan\theta) \}.
\end{aligned}\right\} \quad (23)$$

Assumptions in Regard to the Type Systems

11. The three equations (23) are the conditions of equilibrium for the joint J' in Fig. 2. Three equations of similar type hold for each of the other joints in the same bulkhead, so that each intermediate bulkhead provides, in all, $3N$ equations where N is the number of joints in the polygonal ring.

But, as in the analysis for the parallel tube, on certain assumptions leading to type systems of a particular kind the equilibrium of *every* joint in *every* intermediate bulkhead is ensured provided that three conditions, in all, are satisfied.

Thus, if it is assumed that u, v, w, in so far as they depend on j, have the forms

$$\left.\begin{aligned} u_j &= U_n \cos(nj\alpha + \epsilon), \\ v_j &= V_n \sin(nj\alpha + \epsilon), \\ w_j &= W_n \cos(nj\alpha + \epsilon), \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (24)$$

where n is integral and ϵ is an arbitrary phase constant, the conditions (21) for the equilibrium of a central joint O' will make a' and b' zero in (15), and therefore $u'_{0J} = 0$, unless $n = 1$; when $n = 1$, they demand that $u'_{0J} = u'_j$.

[11] *cf.* C. Smith, Treatise on Algebra, Fifth Ed., end of §259.

Accordingly, when the values (24) are substituted in equations (23), $\cos(nj\alpha+\epsilon)$ or $\sin(nj\alpha+\epsilon)$ can be cancelled out of each, and the three equations

$$\left.\begin{aligned}
0=&(1-\cos\alpha)\,[\,\{\,a^3f^2(1+\Delta)^2+2k_2a^2f^2(1+\Delta)+a\,\}\cos n\alpha\\
&\qquad+\{\,a^4f^2+1+2(k_2+k_3)a^2f^2\,\}(1+\Delta)]\,U_n\\
&+\sin\alpha\,[a^3f^2(1+\Delta)^2+2k_2a^2f^2(1+\Delta)+a\,]\,V_n\sin n\alpha\\
&+c\,[\,\{\,a^3f^2(1+\Delta)^2-1\,\}\cos n\alpha-(a^3f^2-1)(1+\Delta)]\,(W_n+U_n\tan\theta),\\
0=&(1-\cos\alpha)\,[a^3f^2(1+\Delta)^2+2k_2a^2f^2(1+\Delta)+a\,]\,U_n\sin n\alpha\\
&-\sin\alpha\,[\,\{\,a^3f^2(1+\Delta)^2+2k_2a^2f^2(1+\Delta)+a\,\}\cos n\alpha\\
&\qquad-(a^4f^2+1+2k_2a^2f^2)(1+\Delta)]\,V_n\\
&+c\,[a^3f^2(1+\Delta)^2-1\,](W_n+U_n\tan\theta)\sin n\alpha,\\
0=&(1-\cos\alpha)\,[\,\{\,a^2f^2(1+\Delta)^2-a\,\}\cos n\alpha+(a^3f^2-1)(1+\Delta)]\,U_n\\
&+\sin\alpha\,[a^2f^2(1+\Delta)^2-a\,]\,V_n\sin n\alpha\\
&+c\,[\,\{\,a^2f^2(1+\Delta)^2+1\,\}\cos n\alpha-(a^2f^2+1)(1+\Delta)\\
&\qquad+k_1\,\{\,a^2f^2(1+\Delta)^2-(a^2f^2+1)(1+\Delta)+1\,\}\,](W_n+U_n\tan\theta),
\end{aligned}\right\}\quad(25)$$

are obtained which govern the type systems for all values of n, subject to the convention that $k_3=0$ when $n=1$ if radial members are present in every intermediate bulkhead, but $k_3=0$ for all values of n if the radial members are omitted.

12. Again, the operator $[1+\Delta]$ can be eliminated if it is assumed that U_n, V_n, W_n in (24), in so far as they depend on the particular bulkhead in which the joint is situated, are governed by a difference law of the type

$$0=[af(1+\Delta)-\lambda]\,(U_n, V_n, W_n),$$

where λ is a constant; for then, by equations (22*a* and *b*),

$$\left.\begin{aligned}
U_n&=U_\lambda(\lambda/af)^\beta,\\
V_n&=V_\lambda(\lambda/af)^\beta,\\
W_n&=W_\lambda(\lambda/af)^\beta,
\end{aligned}\right\}\quad\ldots\quad(26)$$

where U_λ, V_λ, W_λ are also constants depending on the value of λ, and the operator $[1+\Delta]$ is equivalent to a factor

$$[1+\Delta]\equiv\lambda/af.\quad\ldots\quad(27)$$

On this assumption the three equations (25), on multiplying each throughout by $(af)^{\beta+1}/\lambda^\beta$, become

$$\left.\begin{aligned}
0=&(1-\cos\alpha)\,[a^2f(\lambda^2+2k_2f\lambda+1)\cos n\alpha+\{\,a^4f^2+1+2(k_2+k_3)a^2f^2\,\}\lambda]\,U_\lambda\\
&+\sin\alpha a^2f(\lambda^2+2k_2f\lambda+1)\,V_\lambda\sin n\alpha\\
&+c\,\{\,af(a\lambda^2-1)\cos n\alpha-(a^3f^2-1)\lambda\,\}\,(W_\lambda+U_\lambda\tan\theta),\\
0=&(1-\cos\alpha)\,a^2f(\lambda^2+2k_2f\lambda+1)\,U_\lambda\sin n\alpha\\
&-\sin\alpha\,\{\,a^2f(\lambda^2+2k_2f\lambda+1)\cos n\alpha-(a^4f^2+1+2k_2a^2f^2)\lambda\,\}\,V_\lambda\\
&+caf(a\lambda^2-1)\,(W_\lambda+U_\lambda\tan\theta)\sin n\alpha,\\
0=&(1-\cos\alpha)\,\{\,af(\lambda^2-a)\cos n\alpha+(a^3f^2-1)\lambda\,\}\,U_\lambda\\
&+\sin\alpha af(\lambda^2-a)\,V_\lambda\sin n\alpha\\
&+c\,[af(\lambda^2+1)\cos n\alpha-(a^2f^2+1)\lambda\\
&\qquad+k_1\,\{\,af\lambda^2-(a^2f^2+1)\lambda+af\,\}\,](W_\lambda+U_\lambda\tan\theta),
\end{aligned}\right\}\quad(28)$$

where $k_3=0$ when $n=1$.

On eliminating $U_\lambda(1-\cos\alpha)$, $V_\lambda\sin\alpha$, $c\,(W_\lambda+U_\lambda\tan\theta)$ between these three equations, a three-row determinantal relation is obtained which must be satisfied if those three equations are compatible. This determinant is equivalent to an equation of the sixth degree in λ regarded as a function of n and of the geometric and elastic properties of the structure (α, θ, c, f, k_1, k_2, k_3).

13. Combining assumptions (24) and (26) it follows that displacements specified by

$$\left.\begin{aligned}
u_j&=U_\lambda(\lambda/af)^\beta\cos(nj\alpha+\epsilon),\\
v_j&=V_\lambda(\lambda/af)^\beta\sin(nj\alpha+\epsilon),\\
w_j&=W_\lambda(\lambda/af)^\beta\cos(nj\alpha+\epsilon),
\end{aligned}\right\}\quad\ldots\quad(29)$$

where U_λ, V_λ, W_λ, λ, ϵ are constants and n is an integer, will satisfy the conditions of equilibrium at every joint in every intermediate bulkhead provided that λ, U_λ, V_λ, W_λ are related by (28).

In order to maintain equilibrium at the terminal bulkheads forces must be applied in some definite manner which will be investigated later (§ 22).

Now independent type systems can be obtained from (29) by assigning the following values to n:—

$$\left.\begin{aligned} &n=0,\ 1,\ 2,\ \ldots,\ \tfrac{1}{2}(N-1), \text{ when } N \text{ is odd,}\\ &n=0,\ 1,\ 2,\ \ldots,\ \tfrac{1}{2}N, \text{ when } N \text{ is even,}\end{aligned}\right\} \quad . \quad . \quad (30)$$

where N is the number of joints in the polygonal ring, and with each of these values for n either of the two values

$$\epsilon=0 \text{ or } \epsilon=-\pi/2, \quad . \quad . \quad . \quad . \quad . \quad (31)$$

will lead to different types.

Again, it was indicated in the last section that the three equations (28) lead to a sextic in λ regarded as a function of n. Thus, *provided that for each value of n the roots of the corresponding sextic for λ are all distinct*, twelve independent type systems can, in general, be obtained for each value of n in (30), though as will be shown later, for either of the particular values $n=0$ and $n=\frac{1}{2}N$, if N is even, only six type systems can be obtained. Thus, whether N is even or odd, the assumptions (29) will lead, in all, to $6N$ independent type systems *if the above proviso holds good*.

Condition for the Existence of a Type System of the Form (26)—The Determinantal Equation

14. If

$$\left.\begin{aligned} &\lambda=s+\sqrt{(s^2-1)}=\lambda_1,\\ &\lambda^{-1}=s-\sqrt{(s^2-1)}=\lambda_2,\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (32)$$

so that

on dividing each of the equations (28) by λ and eliminating $U_\lambda(1-\cos\alpha)$, $V_\lambda \sin\alpha$, $c(W_\lambda+U_\lambda\tan\theta)$, the critical determinant for λ is obtained in the form

$$0=D=\begin{vmatrix} 2a^2fs\cos n\alpha+a^4f^2+1 \\ +2a^2f^2\{k_2(1+\cos n\alpha)+k_3\}, & 2a^2f(s+fk_2)\sin n\alpha, & af(a\lambda-\lambda^{-1})\cos n\alpha \\ & & -(a^3f^2-1) \\ 2a^2f(s+fk_2)\sin n\alpha, & -2a^2fs\cos n\alpha+a^4f^2+1 & af(a\lambda-\lambda^{-1})\sin n\alpha \\ & +2a^2f^2k_2(1-\cos n\alpha), & \\ af(\lambda-a\lambda^{-1})\cos n\alpha & af(\lambda-a\lambda^{-1})\sin n\alpha, & 2afs\cos n\alpha-(a^2f^2+1) \\ +(a^3f^2-1), & & +k_1\{2afs-(a^2f^2+1)\} \end{vmatrix} \quad (33)$$

The necessary relationship for the constants U_λ, V_λ, W_λ can then be deduced (making use of the second and third rows in the determinant) in the form

$$\left.\begin{aligned} &U_\lambda(1-\cos\alpha):V_\lambda\sin\alpha:c(W_\lambda+U_\lambda\tan\theta)=\\ &\quad -4a^3f^2s^2(k_1\cos n\alpha+1)\\ &\quad +2afs[a(a^2f^2+1)(k_1+1)\cos n\alpha\\ &\qquad +(k_1+\cos n\alpha)\{a^4f^2+1+2a^2f^2k_2(1-\cos n\alpha)\}]\\ &\quad -(a^2f^2+1)(k_1+1)\{a^4f^2+1+2a^2f^2k_2(1-\cos n\alpha)\}\\ &\qquad +a^2f^2(a+1)^2(1-\cos^2 n\alpha)\\ &:-af\sin n\alpha[4a^2fs^2k_1-2as\{(a^2f^2+1)(k_1+1)-2af^2k_2(k_1+\cos n\alpha)\}\\ &\qquad -2afk_2(a^2f^2+1)(k_1+1)+af(a+1)^2\cos n\alpha-(a^3f^2-1)(a\lambda-\lambda^{-1})]\\ &:-(a^3f^2-1)\{-2a^2fs\cos n\alpha+a^4f^2+1+2a^2f^2k_2(1-\cos n\alpha)\}\\ &\quad +af(\lambda-a\lambda^{-1})\{2a^2fs+2a^2f^2k_2(1-\cos n\alpha)-(a^4f^2+1)\cos n\alpha\}. \end{aligned}\right\} \quad (34)$$

15. On expansion, the determinant (33) can be written as a cubic in s:—

$$
\left.\begin{aligned}
0 = -D = \\
&(s-1)^3\, 8a^5f^3k_1 \\
&+(s-1)^2\, 4a^3f^2\,[\,\{\,4a^2f-a\,(af-1)^2\,\}\,k_1 \\
&\qquad\qquad +2a^2f^2\,\{\,k_2\,(2k_1+1+\cos n\alpha)+k_3\,(k_1\cos n\alpha+1)\,\}\,] \\
&-(s-1)\,2af\,[\,\{\,(a^4f^2-1)^2+4a^3f\,(af-1)^2\,\}\,k_1 \\
&\qquad\qquad +\{\,(a^2f-1)^2+a\,(af-1)^2\,\}\,2a^2f^2k_2\,(2k_1+1+\cos n\alpha) \\
&\qquad\qquad +2a^2f^2k_3\,\{\,k_1\,[2a^2f^2k_2\,(1-\cos n\alpha)+(a^4f^2+1) \\
&\qquad\qquad\qquad\qquad +a\,(a^2f^2-4af+1)\cos n\alpha\,] \\
&\qquad\qquad\qquad +2a^2f^2k_2\,(1-\cos n\alpha)\cos n\alpha \\
&\qquad\qquad\qquad +(a+1)\,(a^3f^2+1)\cos n\alpha-4a^2f\,\}\,] \\
&+k_1\,(a^4f^2-1)^2\,(af-1)^2+2a^2f^2k_2\,(a^2f-1)^2\,(af-1)^2\,(2k_1+1+\cos n\alpha) \\
&+2a^2f^2k_3\,[k_1\,(af-1)^2\,(a^4f^2-2a^2f\cos n\alpha+1)+2a^2f^2k_1k_2\,(af-1)^2\,(1-\cos n\alpha) \\
&\qquad +2a^2f^2k_2\,(a^2f^2-2af\cos n\alpha+1)\,(1-\cos n\alpha) \\
&\qquad +\{\,a^3f^2+1-(a+1)\,af\cos n\alpha\,\}^2],
\end{aligned}\right\} \quad (35)
$$

where the terms in k_3 are omitted when $n=1$ if radial members are present in the intermediate bulkheads and omitted for all values of n if they are absent.

Unless $s=\pm 1$, each root of this cubic equation leads to two possible values for λ, viz., λ_1 and λ_2, which are reciprocals of each other, for if λ_2 replaces λ_1 in (26), (28) and (33) the equation (35) for s is unaffected. The appropriate value for λ must however be used in determining the ratios (34). Thus, *provided that the three roots in s differ from* ± 1 *and are all distinct*, six distinct values of λ can be found for each value of n.

Roots of the Cubic Equation in s

16. Examination of the term in (35) independent of $(s-1)$ shows that this is essentially positive, since k_1, k_2, k_3 are all positive, but that it will vanish (so that $s=1$ is a root of (35)) if either $n=0$ or $k_3=0$ provided also $f=1/a$ or $1/a^2$. These cases require special investigation. Inspection of the term in $(s-1)$ shows that this cannot vanish at the same time unless $a=f=1$ (so that $s=1$ can only be a *double* root of (35) in the case of the parallel tube with identical bays).

The terms in (35) which do not contain k_3 can be arranged in the form

$$
\begin{aligned}
&[\,2af\,(s-1)-(af-1)^2\,]\,[\,2a^2f\,(s-1)-(a^2f-1)^2\,] \\
&\times[\,2a^2fk_1\,(s-1)+(a^2f+1)^2\,k_1+2a^2f^2k_2\,(2k_1+1+\cos n\alpha)\,],
\end{aligned}
\qquad (35a)
$$

while the terms containing k_3 can be arranged in the form

$$
\begin{aligned}
&2a^2f^2k_3\,[k_1\,\{\,(a^4f^2-2a^2fs\cos n\alpha+1)\,(a^2f^2-2afs+1) \\
&\qquad\qquad +2a^2f^2k_2\,(a^2f^2-2afs+1)\,(1-\cos n\alpha)\,\} \\
&\qquad +2a^2f^2k_2\,(a^2f^2-2afs\cos n\alpha+1)\,(1-\cos n\alpha) \\
&\qquad +(1-s^2)\,(a^3f^2-1)^2+\{\,(a^3f^2+1)\,s-(a+1)\,af\cos n\alpha\,\}^2],
\end{aligned}
\qquad (35b)
$$

from which it is clear that $s=-1$ cannot be a root of (35) nor has it any root in the region

$$-1 < s < +1$$

(so that a real value of s leads to two real values of λ), but that there is always one real negative root in the region

$$-\infty < s-1 < -\{\,(a^2f+1)^2+4a^2f^2k_2\,\}/2a^2f,$$

while the other pair of roots are positive if real, and may be either distinct, or equal, or conjugate complex (in which last case the ratios (34) will also be complex).[12] The case in which the roots are equal requires special investigation.

[12] See Appendix.

Special Cases[13]

17. Discarding the assumptions (26) and returning to the equations (25), when $n=0$ these reduce to

$$\left.\begin{aligned} 0 &= (1-\cos\alpha)\,[\,\{\,a^3f^2\,(1+\Delta)+1\,\}\,(1+\Delta+a)+2a^2f^2\,(2k_2+k_3)\,(1+\Delta)\,]\,U_0 \\ &\quad + c\,[\,a^3f^2\,(1+\Delta)+1\,]\,\Delta\,(W_0+U_0\tan\theta), \\ 0 &= \sin\alpha\,[\,a^3f^2\,(1+\Delta)-1\,]\,[\,1+\Delta-a\,]\,V_0, \\ 0 &= (1-\cos\alpha)\,[\,a^2f^2\,(1+\Delta)-1\,]\,[\,1+\Delta+a\,]\,U_0 \\ &\quad + c\,(k_1+1)\,[\,a^2f^2\,(1+\Delta)-1\,]\,\Delta\,(W_0+U_0\tan\theta). \end{aligned}\right\} \quad (36)$$

The first and third of these equations are independent of the second. Taking the second, if $f\neq 1/a^2$, either of the two operators can be taken separately, whence

$$V_0=Pa^\beta+Q\,(a^3f^2)^{-\beta}, \quad . \quad . \quad . \quad . \quad (37)$$

where P and Q are constants. These two solutions are obviously of the form (26) where $\lambda=a^2f$ and $1/a^2f$ respectively; they could have been deduced from (35) and (32).

But if $f=1/a^2$ (*i.e.*, roughly speaking, if the cross-sectional areas of the members vary inversely as their lengths) then the second of (36) takes the form

$$0=[\,1+\Delta-a\,]^2\,V_0,$$

whence

$$V_0=Pa^\beta+Q\beta a^\beta, \quad . \quad . \quad . \quad . \quad . \quad (38)$$

where P and Q are constants [*cf.* (22*a* and *b*)].

The type characterised by P in (37) or (38) represents a rigid body rotation of the structure as a whole involving no action in any member (see §§ 22, 23). The type characterised by Q represents a twist of the structure in which each bulkhead is rotated relatively to the next; the angle of twist would be zero at the point P (Fig. 3).

Again, operating on the first and third of (36) so as to eliminate U_0, if $f\neq 1/a$,

$$\begin{aligned} 0=\Delta\,[\,a^2f^2\,(1+\Delta)-1\,]\,[k_1\,\{\,a^3f^2\,(1+\Delta)+1\,\}\,(1+\Delta+a) \\ +(k_1+1)\,2a^2f^2\,(2k_2+k_3)\,(1+\Delta)\,]\,(W_0+U_0\tan\theta). \end{aligned} \quad (39)$$

Two solutions come from taking the first two operators separately, whence

$$\begin{aligned} W_0+U_0\tan\theta&=R+S\,(a^2f^2)^{-\beta}, \\ U_0=-S\,[c\,(a+1)\,(a^2f^2-1)\,(a^2f^2)^{-\beta}]/[\,(1-\cos\alpha)\,\{\,(a+1)\,(a^3f^2+1) \\ +2a^2f^2\,(2k_2+k_3)\,\}\,], \end{aligned} \quad (40)$$

where R and S are constants. These solutions are of the form (26) and could have been deduced from (35) and (32).

But if $f=1/a$ (*i.e.*, if the cross-sectional areas of the members vary as their lengths) then (39) takes the form

$$0=\Delta^2\,[k_1\,\{\,a\,(1+\Delta)+1\,\}\,(1+\Delta+a)+(k_1+1)\,2\,(2k_2+k_3)\,(1+\Delta)]\,(W_0+U_0\tan\theta),$$

and then two solutions come from

$$0=\Delta^2\,(W_0+U_0\tan\theta),$$

whence

$$\left.\begin{aligned} W_0+U_0\tan\theta&=R+S\beta, \\ U_0=-S\,[c\,(a+1)]/[(1-\cos\alpha)\,\{\,(a+1)^2+2\,(2k_2+k_3)\,\}\,], \end{aligned}\right\} \quad (41)$$

where R and S are constants.

The type characterised by R in (40) or (41) represents a rigid body translation of the structure as a whole in the z-direction. The type characterised by S represents an extension of the structure in the z-direction accompanied by radial contractions; the displacement of the point P (Fig. 3) would be zero.

[13] §§17–20 are inserted for the complete understanding of the equations; the general forms covering all special cases unless $a=f=1$ will be found in §21.

Another pair of solutions, which is of the form (26) for all values of f and a, comes from the third operator in (39):—

$$O=[k_1\{a^3f^2(1+\Delta)+1\}(1+\Delta+a) + (k_1+1)2a^2f^2(2k_2+k_3)(1+\Delta)](W_0+U_0\tan\theta). \quad (42)$$

The types (37) or (38) are associated only with V_0, and therefore with $\epsilon=-\pi/2$ only (§13). The types (40) or (41) and the types derived from (42) are associated with U_0 and W_0 only, and therefore only with $\epsilon=0$. Thus the value $n=0$ provides, in all, six distinct types.

18. If N is even and $n=\frac{1}{2}N$, the first and third of (28) are independent of the second. It is easily verified that two types associated with $V_{\frac{1}{2}N}$ only, and therefore only with $\epsilon=-\pi/2$,* are derived from

$$s-1=-\{(a^2f+1)^2+4a^2f^2k_2\}/2a^2f, \quad (43)$$

while four types associated only with $U_{\frac{1}{2}N}$ and $W_{\frac{1}{2}N}$ and therefore with $\epsilon=0$ only* are derived, in general, from

$$O=\{-2a^2fs+a^4f^2+1+2a^2f^2k_3\}\{(k_1-1)2afs-(k_1+1)(a^2f^2+1)\} - [a^2f^2\{4as^2-(1+a)^2\}+af(a^3f^2-1)(a-1)2s-(a^3f^2-1)^2]. \quad (44)$$

The special solutions when $k_3=0$ and $f=1/a$ or $1/a^2$ or $1/a^{3/2}$ are given in §20, and the special solutions when $k_3\neq0$, but the constants are so related that the two values of s derived from (44) are identical, are given in §21.

Thus the value $n=\frac{1}{2}N$ when N is even, provides, in all, six distinct type systems.

19. When $k_3=0$, either by reason of absence of radial members in the intermediate bulkheads or (by the convention of §11) when $n=1$, the right hand side of equation (35) factorises as shown in (35a); provided that $a\neq1$ and that $f\neq1/a$ or $1/a^2$ or $1/a^{3/2}$, three distinct values of s can then be found. The analysis which covers all cases is obtained from equations (25).

Multiplying the first and second of (25) by $\sin n\alpha$ and $(1+\cos n\alpha)$ respectively and subtracting,

$$0=[a^3f^2(1+\Delta)-1]\{[1+\Delta-a][U_n(1-\cos\alpha)\sin n\alpha+V_n(1-\cos n\alpha)\sin\alpha] - 2[1+\Delta-a]V_n\sin\alpha+[\Delta+2]c(W_n+U_n\tan\theta)\sin n\alpha\}; \quad (45)$$

the second of (25) may be written

$$0=[a^3f^2(1+\Delta)^2+a+2k_2a^2f^2(1+\Delta)][U_n(1-\cos\alpha)\sin n\alpha+V_n(1-\cos n\alpha)\sin\alpha] - [a^3f^2(1+\Delta)-1][1+\Delta-a]V_n\sin\alpha + [a^3f^2(1+\Delta)^2-1]c(W_n+U_n\tan\theta)\sin n\alpha, \quad (46)$$

and the third of (25), on multiplying by $\sin n\alpha$, becomes

$$0=[\{a^2f^2(1+\Delta)^2-a\}\cos n\alpha+(a^3f^2-1)(1+\Delta)][U_n(1-\cos\alpha)\sin n\alpha + V_n(1-\cos n\alpha)\sin\alpha] + [a^2f^2(1+\Delta)+1][1+\Delta-a]V_n\sin\alpha(1-\cos n\alpha) + [\{a^2f^2(1+\Delta)^2+1\}\cos n\alpha-(a^2f^2+1)(1+\Delta) + k_1\{a^2f^2(1+\Delta)-1\}\Delta]c(W_n+U_n\tan\theta)\sin n\alpha. \quad (47)$$

Eliminating the terms in V_n between (45) and (46),

$$0=[\{a^3f^2(1+\Delta)+1\}(1+\Delta+a)+4k_2a^2f^2(1+\Delta)][U_n(1-\cos\alpha)\sin n\alpha + V_n(1-\cos n\alpha)\sin\alpha] + [a^3f^2(1+\Delta)+1]\Delta c(W_n+U_n\tan\theta)\sin n\alpha; \quad (48)$$

similarly, operating on (45) and (47), so as to eliminate the terms in V_n,

$$=0[a^3f^2(1+\Delta)-1][a^2f^2(1+\Delta)-1]\{[1+\Delta+a](1+\cos n\alpha)[U_n(1-\cos\alpha)\sin n\alpha + V_n(1-\cos n\alpha)\sin\alpha] + (2k_1+1+\cos n\alpha)\Delta c(W_n+U_n\tan\theta)\sin n\alpha\}. \quad (49)$$

* There would be no advantage here in substituting $(j\alpha-\zeta)$ for $j\alpha$, if $\zeta\neq0$, as the types associated with the two values for ϵ, though existing, would not be distinct (§3).

Operating on (48) and (49) so as to eliminate $c\,(W_n + U_n \tan\theta)$,

$$0 = [a^2f^2\,(1+\Delta)-1]\,[a^3f^2\,(1+\Delta)-1]\,[k_1\{a^2f^2\,(1+\Delta)+1\}\,(1+\Delta+a) + (2k_1+1+\cos n\alpha)\,2k_2a^2f^2\,(1+\Delta)]\,[U_n\,(1-\cos\alpha)\sin n\alpha + V_n\,(1-\cos n\alpha)\sin\alpha]. \quad . \quad . \quad . \quad (50)$$

Corresponding to the third operator in square brackets there are always two distinct solutions of the form (26) where the values of λ (here negative) are given by (27); these lead in general to four distinct type systems for each value of n, since ϵ can have either of the values in (31). The same values for λ would have been obtained by equating to zero the third factor in (35a). Corresponding to the other two operators, on substituting in (45), (46) and (47), it can be deduced that

$$\left.\begin{aligned} 0 &= [a^2f^2\,(1+\Delta)-1]\,[a^3f^2\,(1+\Delta)-1]\,\{U_n\,(1-\cos\alpha)\sin n\alpha \\ &\qquad + V_n\,(1-\cos n\alpha)\sin\alpha\}, \\ 0 &= [a^2f^2\,(1+\Delta)-1]\,[a^3f^2\,(1+\Delta)-1]\,\Delta\,(W_n + U_n\tan\theta), \\ 0 &= [a^2f^2\,(1+\Delta)-1]\,[a^3f^2\,(1+\Delta)-1]\,\Delta\,[1+\Delta-a]\,(U_n \text{ or } V_n). \end{aligned}\right\} \quad (51)$$

20. Equations (51) are the general difference equations when $k_3 = 0$, either by absence of radial members in the intermediate bulkheads or (by the convention of § 11) when $n = 1$. Six different cases arise in their solution:—

(1) *If $a \neq 1$ and $f \neq 1/a$ or $1/a^2$ or $1/a^{3/2}$* all the solutions are of the form (26); they are given here for comparison with the other cases.

Corresponding to the operator Δ,

$$\left.\begin{aligned} U_n\,(1-\cos\alpha) &= K\,(1-\cos n\alpha), \\ V_n \sin\alpha &= -K\sin n\alpha, \\ c\,(W_n + U_n\tan\theta) &= K\,(a-1), \end{aligned}\right\} \quad . \quad . \quad . \quad (52)$$

where K is a constant.

Corresponding to the operator $[1+\Delta-a]$,

$$\left.\begin{aligned} U_n\,(1-\cos\alpha) &= Ha^\beta\,(1-\cos n\alpha), \\ V_n \sin\alpha &= -Ha^\beta \sin n\alpha, \\ c\,(W_n + U_n\tan\theta) &= 0, \end{aligned}\right\} \quad . \quad . \quad . \quad (53)$$

where H is a constant.

Corresponding to the operator $[a^3f^2\,(1+\Delta)-1]$,

$$\left.\begin{aligned} U_n\,(1-\cos\alpha) &= G\,(a^3f^2)^{-\beta}\,[k_1\,(a-1)\,(a^3f^2-1)\,(a^4f^2+1+2k_2a^2f^2) \\ &\quad + 2k_2a^2f^2\,\{(a^4f^2+1)\cos n\alpha - (a^2f^2+1)\,a\} \\ &\quad - (a+1)\,\{a^7f^4 - a^3f^2\,(a+1)\cos n\alpha + 1\}]\,(1-\cos n\alpha), \\ V_n \sin\alpha &= -G\,(a^3f^2)^{-\beta}\,[k_1\,(a-1)\,(a^3f^2-1)\,(a^4f^2+1+2k_2a^2f^2) \\ &\quad + 2k_2a^2f^2\,\{(a^4f^2+1)\cos n\alpha - (a^2f^2+1)\,a\} \\ &\quad - (a+1)^2\,a^3f^2\,(1-\cos n\alpha)]\sin n\alpha, \\ c\,(W_n + U_n\tan\theta) &= -G\,(a^3f^2)^{-\beta}\,(a+1)\,(a^4f^2-1)\,(a^4f^2+1+2k_2a^2f^2)\,(1-\cos n\alpha), \end{aligned}\right\} \quad (54)$$

where G is a constant.

Corresponding to the operator $[a^2f^2\,(1+\Delta)-1]$,

$$\left.\begin{aligned} U_n\,(1-\cos\alpha) &= F\,(a^2f^2)^{-\beta}\,[\{(a+1)^2 + 2k_2\,(a^2f^2+1)\}\,a^2f^2\,(1-\cos n\alpha) \\ &\quad + (a+1)\,(a^2f^2-1)\,(a^3f^2-1)], \\ V_n \sin\alpha &= -F\,(a^2f^2)^{-\beta}\,\{(a+1)^2 + 2k_2\,(a^2f^2+1)\}\,a^2f^2 \sin n\alpha, \\ c\,(W_n + U_n\tan\theta) &= F\,(a^2f^2)^{-\beta}\,(a^3f^2-1)\,\{(a+1)\,(a^3f^2+1) + 4a^2f^2k_2\}, \end{aligned}\right\} \quad (55)$$

where F is a constant.

When $n = 1$ (see §§ 22 and 23), the solution (52), characterised by K, represents a rigid body translation of the structure as a whole, the axis of z being displaced parallel to itself; the solution (53), characterised by H, represents a rigid body rotation of the structure about the point P; the solution (54), characterised by G, represents uniform flexure of the structure under the action of terminal couples; the solution (55), characterised by F, represents uniform shearing of the structure (accompanied by uniformly varying bending moment), the external forces being equivalent in action to a pure shear applied at the point P.

(2) *If* $a \neq 1$ *but* $f = 1/a$ (*i.e.*, if the cross-sectional areas of the members vary as their lengths), the solutions (55) and (52) are identical; the special solution in place of (55) corresponds to an operator Δ^2, and is of the form

$$\left.\begin{aligned} U_n(1-\cos\alpha) &= F[\beta\{(a+1)^2+4k_2\}(1-\cos n\alpha)-(a^2-1)],\\ V_n\sin\alpha &= -F\beta\{(a+1)^2+4k_2\}\sin n\alpha,\\ c(W_n+U_n\tan\theta) &= F[\beta\{(a+1)^2+4k_2\}(a-1)-(a+1)(a^2+1+2k_2)]. \end{aligned}\right\} \quad (56)$$

The other solutions are obtained from (52) and (53) and by writing $f = 1/a$ in (54).

(3) *If* $a \neq 1$ *but* $f = 1/a^2$ (*i.e.*, if the cross-sectional areas of the members vary inversely as their lengths), the solutions (54) and (53) are identical, the special solution in place of (54) corresponds to the operator $[1+\Delta-a]^2$, and is of the form

$$\left.\begin{aligned} U_n(1-\cos\alpha) &= Ga\beta[\beta\{2k_1(a-1)^2(a^2+k_2)+2k_2(a^2+1-2a\cos n\alpha)\\ &\qquad +a^2(a+1)^2(1-\cos n\alpha)\}+a^2(a^2-1)](1-\cos n\alpha),\\ V_n\sin\alpha &= -Ga\beta\beta\{2k_1(a-1)^2(a^2+k_2)+2k_2(a^2+1-2a\cos n\alpha)\\ &\qquad +a^2(a+1)^2(1-\cos n\alpha)\}\sin n\alpha,\\ c(W_n+U_n\tan\theta) &= -Ga\beta 2a(a+1)(a^2+k_2)(1-\cos n\alpha). \end{aligned}\right\} \quad (57)$$

The other solutions are obtained from (52) and (53) and by writing $f = 1/a^2$ in (55).

(4) *If* $a \neq 1$ *but* $f^2 = 1/a^3$ (*i.e.*, if the cross-sectional areas of the members are constant), the first two factors in (35a) are identical, so that the two positive values of s are equal ($s \neq 1$); solutions (55) and (53) and also (54) and (52) are then identical. The special solution in place of (55) corresponds to the operator $[1+\Delta-a]^2$ and is of the form

$$\left.\begin{aligned} U_n(1-\cos\alpha) &= Fa\beta[\beta(a+a^2+2k_2)(a+1)(1-\cos n\alpha)+a(a^2-1)],\\ V_n\sin\alpha &= -Fa\beta\beta(a+a^2+2k_2)(a+1)\sin n\alpha,\\ c(W_n+U_n\tan\theta) &= -Fa\beta 2a(a+a^2+2k_2); \end{aligned}\right\} \quad (58)$$

while the special solution in place of (54) corresponds to an operator Δ^2 and is of the form

$$\left.\begin{aligned} U_n(1-\cos\alpha) &= G[\beta(a+a^2+2k_2)(a+1)(1-\cos n\alpha)-a(a^2-1)](1-\cos n\alpha),\\ V_n\sin\alpha &= -G\beta(a+a^2+2k_2)(a+1)(1-\cos n\alpha)\sin n\alpha,\\ c(W_n+U_n\tan\theta) &= G[\beta(a+a^2+2k_2)(a^2-1)(1-\cos n\alpha)+a(a-1)(a^2-1)\cos n\alpha\\ &\qquad -(a+a^2+2k_2)\{k_1(a-1)^2+a^2+1-2a\cos n\alpha\}]. \end{aligned}\right\} \quad (59)$$

The other two solutions are (52) and (53).

(5) *If* $a = 1$ (*so that* $\theta = 0$) *but* $f \neq 1$ (*i.e.*, for the parallel tube in which the elastic properties vary from bay to bay according to a geometric law), the fundamental equations are

$$\left.\begin{aligned} 0 &= [f^2(1+\Delta)-1]^2\{U_n(1-\cos\alpha)\sin n\alpha+V_n(1-\cos n\alpha)\sin\alpha\},\\ 0 &= [f^2(1+\Delta)-1]^2\Delta W_n,\\ 0 &= [f^2(1+\Delta)-1]^2\Delta^2(U_n \text{ or } V_n). \end{aligned}\right\} \quad (60)$$

Two solutions are obtained by putting $a = 1$ in (52) and (54); the special solution in place of (53) is

$$\left.\begin{aligned} U_n(1-\cos\alpha) &= H\beta(1-\cos n\alpha),\\ V_n\sin\alpha &= -H\beta\sin n\alpha,\\ cW_n &= -H; \end{aligned}\right\} \quad . \quad . \quad . \quad (61)$$

while the special solution in place of (55) is

$$\left.\begin{aligned} U_n(1-\cos\alpha) &= Ff^{-2\beta}[\beta\{(f^2-1)^3-(f^2+1+2k_2f^2)(f^4-1)\}(1-\cos n\alpha)\\ &\qquad -(f^2+1+2k_2f^2)\{k_1(f^2-1)^2+(f^2+1)^2-4f^2\cos n\alpha\}\\ &\qquad +(f^2-1)^2(f^2+1)-2\beta(f^2-1)^3](1-\cos n\alpha),\\ V_n\sin\alpha &= -Ff^{-2\beta}[\beta\{(f^2-1)^3-(f^2+1+2k_2f^2)(f^4-1)\}(1-\cos n\alpha)\\ &\qquad -(f^2+1+2k_2f^2)\{k_1(f^2-1)^2+(f^2+1)^2-4f^2\cos n\alpha\}\\ &\qquad +(f^2-1)^2(f^2+1)]\sin n\alpha,\\ cW_n &= -Ff^{-2\beta}[2\beta(f^2-1)^2(f^2+1+2k_2f^2)\\ &\qquad +(f^2-1)f^2\{4+2k_2(f^2+1)\}](1-\cos n\alpha). \end{aligned}\right\} \quad (62)$$

(6) *If* $a=f=1$ (*i.e.*, for the parallel tube with identical bays), the fundamental equations are

$$0=\Delta^2\,[U_n\,(1-\cos\alpha)\sin n\alpha+V_n\,(1-\cos n\alpha)\sin\alpha],$$
$$0=\Delta^3 W_n,$$
$$0=\Delta^4\,(U_n \text{ or } V_n);$$

the solutions of these equations have been fully discussed elsewhere.[14] It may be noted here that they are of the general form (22*b*) where $p=1$ and $q=4$ in conjunction with U_n and V_n and $q=3$ in conjunction with W_n.

21. It remains to discuss the case in which, whatever the value of k_3, owing to the particular relative values of the constants involved, the two positive roots of s in (35) are identical for some value of n. Corresponding to the double root, only two positive values of λ, viz., λ_1 and λ_2, instead of four can be obtained from the assumption of § 12. The two negative values are always obtainable.

This is obviously a case in which (45) with an extra term in k_3 together with (46) and (47) would lead to difference equations of the class

$$0=[af\,(1+\Delta)-\lambda_1]^2\,[af\,(1+\Delta)-\lambda_2]^2\,(U_n,\ V_n,\ W_n). \quad . \quad . \quad (64)$$

The case of a single root $s=1$ corresponds to the first operator only with $\lambda_1=1$, and is included in the following argument.

Taking the operator $[af\,(1+\Delta)-\lambda_1]^2$, a first solution is of the form (26) where $\lambda=\lambda_1$. If the determinant (33) is written in brief in the form

$$D=\begin{vmatrix} x_1, & y_1, & z_1 \\ x_2, & y_2, & z_2 \\ x_3, & y_3, & z_3 \end{vmatrix}=0, \quad . \quad . \quad . \quad . \quad (65)$$

and X, Y, Z denote the minors of x, y, z, then

$$\begin{aligned} &U_\lambda\,(1-\cos\alpha):\ V_\lambda\sin\alpha:\ c\,(W_\lambda+U_\lambda\tan\theta) \\ &=X_1:\ -Y_1:\ Z_1=X_2:\ -Y_2:\ Z_2=X_3:\ -Y_3:\ Z_3. \quad . \quad . \quad (66)\end{aligned}$$

A second solution is of the form (*cf.* equation (22*b*))

$$\left.\begin{aligned} U_n&=U_\lambda\beta\,(\lambda_1/af)^\beta+U'_\lambda\,(\lambda_1/af)^\beta, \\ V_n&=V_\lambda\beta\,(\lambda_1/af)^\beta+V'_\lambda\,(\lambda_1/af)^\beta, \\ W_n&=W_\lambda\beta\,(\lambda_1/af)^\beta+W'_\lambda\,(\lambda_1/af)^\beta, \end{aligned}\right\} \quad . \quad . \quad . \quad (67)$$

where U_λ, V_λ, W_λ, U'_λ, V'_λ, W'_λ are constants to be determined.[15]

Substituting these expressions in (25) and multiplying throughout by $(af)^{\beta+1}/\lambda^\beta$, in each equation a series of terms independent of β containing all six constants is obtained, together with a series of terms multiplied by $(\beta+1)$ containing only U_λ, V_λ, W_λ. Since these equations must hold for *all* values of β these last terms must vanish separately, which leads to the condition that U_λ, V_λ, W_λ, in (67) are related as in (66).

On writing

$$\left.\begin{aligned} s&=\cosh\mu, \\ \sqrt{(s^2-1)}&=\sinh\mu, \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (68)$$

so that

it follows that

$$\left.\begin{aligned} &a\lambda_1-\lambda_1^{-1}=(a-1)\ \cosh\mu+(a+1)\sinh\mu, \\ &\text{while} \\ &a\lambda_1+\lambda_1^{-1}=(a-1)\ \sinh\mu+(a+1)\cosh\mu=d\,(a\lambda_1-\lambda_1^{-1})/d\mu, \\ &\text{and} \\ &\lambda_1-a\lambda_1^{-1}=-(a-1)\ \cosh\mu+(a+1)\sinh\mu, \\ &\text{while} \\ &\lambda_1+a\lambda_1^{-1}=-(a-1)\ \sinh\mu+(a+1)\cosh\mu=d\,(\lambda_1-a\lambda_1^{-1})/d\mu. \end{aligned}\right\} \quad (69)$$

[14] Proc. Roy. Soc. A, Vol. 139, p. 475ff., § 26, and in Mr. J. B. Owen's work (T.3407b).

[15] The values for U'_λ, V'_λ, W'_λ are, of course, arbitrary to the extent that they may be increased or decreased by any multiple of the first solution.

In this notation the terms in (25) which do not contain β lead to three equations :—

$$\left.\begin{aligned} 0 = (1-\cos\alpha)\,(U'_\lambda x_1 + U_\lambda dx_1/d\mu) + \sin\alpha\,(V'_\lambda y_1 + V_\lambda dy_1/d\mu) \\ + c\,\{\,(W'_\lambda + U'_\lambda \tan\theta)\,z_1 + (W_\lambda + U_\lambda \tan\theta)\,dz_1/d\mu\,\}\,, \end{aligned}\right\} \quad (70)$$

and two similar equations with suffixes 2 and 3 instead of 1, which must be satisfied by U'_λ, V'_λ, W'_λ.

The assumption that

$$\left.\begin{aligned} &U'_\lambda\,(1-\cos\alpha) : V'_\lambda \sin\alpha : c\,(W'_\lambda + U'_\lambda \tan\theta) = dX_1/d\mu : -dY_1/d\mu : dZ_1/d\mu, \\ &\text{while} \\ &U_\lambda\,(1-\cos\alpha) : V_\lambda \sin\alpha : c\,(W_\lambda + U_\lambda \tan\theta) = X_1 : -Y_1 : Z_1, \end{aligned}\right\} \quad (71)$$

will be justified provided that equations (70) are then satisfied. Substituting from (71), the equations (70) reduce to the conditions

$$\left.\begin{aligned} 0 &= d\,(x_1 X_1 - y_1 Y_1 + z_1 Z_1)/d\mu, \\ 0 &= d\,(x_2 X_1 - y_2 Y_1 + z_2 Z_1)/d\mu, \\ 0 &= d\,(x_3 X_1 - y_3 Y_1 + z_3 Z_1)/d\mu. \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (72)$$

The second and third of these conditions are automatically satisfied in virtue of (65), while the first is the condition

$$0 = dD/d\mu = \sinh\mu\, dD/ds\,; \quad . \quad . \quad . \quad . \quad (73)$$

that is to say, the assumption (71) is justified in the case either of a repeated root of (35), or when $s=1$ ($\mu=0$). *The forms* (67) *and* (71) *are therefore the general forms for the second solution in all special cases which arise unless* $a=f=1$.

A similar argument would have justified the use of X_2, Y_2, Z_2, or X_3, Y_3, Z_3, in place of X_1, Y_1, Z_1 in (71).

Using the forms given in (71), the ratios $U_\lambda : V_\lambda : W_\lambda$ are obtained by putting $\lambda=\lambda_1$ in (34) while the ratios $U'_\lambda : V'_\lambda : W'_\lambda$ are given by

$$\left.\begin{aligned} &U'_\lambda\,(1-\cos\alpha) : V'_\lambda \sin\alpha : c\,(W'_\lambda + U'_\lambda \tan\theta) = \\ &-af\,(\lambda_1 - \lambda_1^{-1})\,[\,4a^2fs\,(k_1\cos n\alpha + 1) - a\,(a^2f^2+1)\,(k_1+1)\cos n\alpha \\ &\qquad - (k_1 + \cos n\alpha)\,\{\,a^4f^2 + 1 + 2a^2f^2k_2\,(1-\cos n\alpha)\,\}\,] \\ &: -af\sin n\alpha\,[\,a\,(\lambda_1 - \lambda_1^{-1})\,\{\,4afsk_1 - (a^2f^2+1)\,(k_1+1) + 2af^2k_2\,(k_1+\cos n\alpha)\,\} \\ &\qquad - (a^3f^2-1)\,(a\lambda_1 + \lambda_1^{-1})\,] \\ &: a^2f\,(\lambda_1 - \lambda_1^{-1})\,\{\,(a^3f^2-1)\cos n\alpha + af\,(\lambda_1 - a\lambda_1^{-1})\,\} \\ &\quad + af\,(\lambda_1 + a\lambda_1^{-1})\,\{\,2a^2fs + 2a^2f^2k_2\,(1-\cos n\alpha) - (a^4f^2+1)\cos n\alpha\,\}\,. \end{aligned}\right\} \quad (74)$$

By taking the second operator in (64) similar forms in which λ_2 replaces λ_1 can be obtained. The sign of μ must be changed during the argument, but this does not affect the final result.

Forces Imposed at the Terminal Bulkheads

22. In order to maintain equilibrium under a type system of displacements, forces must be imposed at the joints of the terminal bulkheads. The formulæ for these forces can be developed by considering the equilibrium of the joint J (Fig. 2). If J is a joint in the left end bulkhead, component forces R_j, T_j, Z_j acting in the same direction as the displacements u_j, v_j, w_j must be imposed at the joint J such that

$$\left.\begin{aligned} -R_j &= r\,\{\,(a-1)\,T_{JJ'} + (a\cos\alpha - 1)\,(T_{JK'} + T_{JI'}) - (1-\cos\alpha)\,(T_{JK} + T_{JI}) - T_{OJ}\,\}\,, \\ -T_j &= r\sin\alpha\,\{\,a\,(T_{JK'} - T_{JI'}) + (T_{JK} - T_{JI})\,\}\,, \\ -Z_j &= cr\,(T_{JK'} + T_{JJ'} + T_{JI'}); \end{aligned}\right\} \quad (75)$$

but if J is a joint in the right end bulkhead, forces must be imposed in the same direction such that

$$\left.\begin{aligned} R_j &= r\,\{\,(a-1)\,T_{JJ'} + (a\cos\alpha - 1)\,(T_{JK'} + T_{JI'})\,\} + rT_{OJ},* \\ T_j &= r'\sin\alpha\,(T_{JK'} + T_{JI'}), \\ Z_j &= cr\,(T_{JK'} + T_{JJ'} + T_{JI'}). \end{aligned}\right\} \quad . \quad (76)$$

* The last term rT_{OJ} is only required if the radial members are omitted in the intermediate bulkheads and then only provided $n \neq 1$.

Substituting for the tension coefficients expressions of type (16), (17), (18), (19) and for the displacements the forms (24), and using the notation of §10, it follows that in every type system, if the βth bulkhead is a left end bulkhead then component forces must be imposed at the joints such that

$$\left.\begin{aligned} R_j &= R_n \cos(nj\alpha+\epsilon),\\ T_j &= T_n \sin(nj\alpha+\epsilon),\\ Z_j &= Z_n \cos(nj\alpha+\epsilon), \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (77)$$

where R_n, T_n, Z_n are constants given by

$$\begin{aligned} -R_n = 2\Omega_{do} r_o^2 (a^2f^2)^\beta \big[&(a-1)\, k_1 \big[1+\Delta-1\big]\, c\,(W_n + U_n \tan\theta)\\ &-(1-\cos\alpha)\, 2k_2 \{ (1+\cos n\alpha)\, U_n (1-\cos\alpha) + \sin n\alpha\, V_n \sin\alpha \}\\ &+(a\cos\alpha - 1)\{ \big[(1+\Delta)\cos n\alpha + a\big]\, U_n (1-\cos\alpha)\\ &\qquad + \sin n\alpha \big[1+\Delta\big]\, V_n \sin\alpha\\ &\qquad + \big[(1+\Delta)\cos n\alpha - 1\big]\, c\,(W_n + U_n\tan\theta)\}\\ &-2k_3 (1-\cos\alpha)^2 U_n \big], \end{aligned}$$

$$\begin{aligned} +T_n = 2\Omega_{do} r_o^2 (a^2f^2)^\beta \sin\alpha \big[&a\{ \sin n\alpha \big[1+\Delta\big]\, U_n (1-\cos\alpha)\\ &\qquad -\big[(1+\Delta)\cos n\alpha - a\big]\, V_n \sin\alpha\\ &\qquad +\sin n\alpha \big[1+\Delta\big]\, c\,(W_n + U_n\tan\theta)\}\\ &+2k_2 \{ U_n (1-\cos\alpha)\sin n\alpha + V_n \sin\alpha (1-\cos n\alpha)\}\big], \end{aligned}$$

$$\begin{aligned} -Z_n = 2\Omega_{do} c r_o^2 (a^2f^2)^\beta \big[&k_1 \big[1+\Delta-1\big]\, c\,(W_n + U_n\tan\theta)\\ &+\big[(1+\Delta)\cos n\alpha + a\big]\, U_n (1-\cos\alpha) + \sin n\alpha \big[1+\Delta\big]\, V_n \sin\alpha\\ &+\big[(1+\Delta)\cos n\alpha - 1\big]\, c\,(W_n + U_n\tan\theta)\big]. \end{aligned}$$

. . . (78)

Similarly, in every type system, if the βth bulkhead is a right end bulkhead, then component forces given by (77) must be imposed at the joints of this bulkhead, where

$$\begin{aligned} R_n = 2\Omega_{do} r_o^2 (a^2f^2)^\beta \big[&(a-1)\, k_1 \big[1+\Delta-1\big]\, c\,(W_n + U_n\tan\theta)\\ &+(a\cos\alpha - 1)\{ \big[(1+\Delta)\cos n\alpha + a\big]\, U_n (1-\cos\alpha)\\ &\qquad + \sin n\alpha \big[1+\Delta\big]\, V_n \sin\alpha\\ &\qquad + \big[(1+\Delta)\cos n\alpha - 1\big]\, c\,(W_n + U_n\tan\theta)\}\\ &+2k_3 U_n (1-\cos\alpha)^{2*}\big], \end{aligned}$$

$$\begin{aligned} -T_n = 2\Omega_{do} r_o^2 (a^2f^2)^\beta \sin\alpha \big[&\sin n\alpha \big[1+\Delta\big]\, U_n (1-\cos\alpha)\\ &-\big[(1+\Delta)\cos n\alpha - a\big]\, V_n \sin\alpha + \sin n\alpha \big[1+\Delta\big]\, c\,(W_n + U_n\tan\theta)\big], \end{aligned}$$

$Z_n = -Z_n$ in (78).

. . . . . (79)

In the general case U_n, V_n, W_n are of the form (26), so that $\big[1+\Delta\big]$ can be replaced as in (27), but in the special cases indicated in §§17, 20 and 21, the special forms must be used.

Total External Actions in a Type System

23. If the βth bulkhead is a right end bulkhead then the total applied shear on the bulkhead face in the direction Ox is given by

$$S_x = \Sigma_j \big[R_j \cos j\alpha - T_j \sin j\alpha\big];$$

this is zero in virtue of (77) unless $n=1$ and $\epsilon=0$, in which case

$$S_x = \tfrac{1}{2}N (R_1 - T_1). \quad . \quad . \quad . \quad . \quad . \quad (80)$$

Similarly, the total applied shear in the direction Oy is given by

$$S_y = \Sigma_j \big[R_j \sin j\alpha + T_j \cos j\alpha\big];$$

this is zero unless $n=1$ and $\epsilon = -\pi/2$, in which case

$$S_y = \tfrac{1}{2}N (R_1 - T_1). \quad . \quad . \quad . \quad . \quad . \quad (80a)$$

The total pull applied on the bulkhead face in the direction OZ is

$$P = \Sigma_j \big[Z_j\big];$$

* This last term is only required when the radial members are omitted in the intermediate bulkheads, and then only provided $n \neq 1$.

this is zero unless $n=0$, in which case

$$P=NZ_0. \qquad (80b)$$

The total applied couple about the axis Oy is

$$M_y=\Sigma_j\,[Z_j r\cos j\alpha\,];$$

this is zero unless $n=1$ and $\epsilon=0$, in which case

$$M_y=\tfrac{1}{2}NrZ_1. \qquad (80c)$$

Similarly, the total applied couple about the axis Ox is

$$M_x=\Sigma_j\,[Z_j r\sin j\alpha\,];$$

this is zero unless $n=1$ and $\epsilon=-\pi/2$, in which case

$$M_x=\tfrac{1}{2}NrZ_1. \qquad (80d)$$

Finally, the total applied torque is

$$C=\Sigma_j\,[rT_j\,];$$

this is zero unless $n=0$ and $\epsilon=-\pi/2$, in which case

$$C=-NrT_0. \qquad (80e)$$

Expansion of the Arbitrarily Specified Terminal Conditions

24. The expansion of the arbitrarily specified displacements or forces at the terminal bulkheads in quasi-Fourier series has been fully explained elsewhere; only a short summary is needed here.

If u_j, v_j, w_j are the arbitrarily specified component displacements at the joint J in the left end bulkhead, then

$$u_j=\Sigma_n\,[A_n\cos nj\alpha+B_n\sin nj\alpha\,], \qquad (81)$$

where the coefficients

$$A_0,\ A_1,\ A_2,\ \ldots,\ A_{\frac{1}{2}(N-1)} \text{ or } A_{\frac{1}{2}N} \text{ according as } N \text{ is odd or even,}$$

and

$$B_1,\ B_2,\ \ldots,\ B_{\frac{1}{2}(N-1)} \text{ or } B_{\frac{1}{2}N-1} \text{ according as } N \text{ is odd or even,}$$

are calculated from the formulæ

$$\left.\begin{aligned} A_0&=(1/N)\,\Sigma_j\,[u_j],\\ A_n&=(2/N)\,\Sigma_j\,[u_j\cos nj\alpha\,]\quad(0<n<\tfrac{1}{2}N),\\ A_{\frac{1}{2}N}&=(1/N)\,\Sigma_j\,[u_j\cos j\pi\,],\\ B_n&=(2/N)\,\Sigma_j\,[u_j\sin nj\alpha\,]. \end{aligned}\right\} \qquad (82)$$

v_j and w_j can be similarly represented:—

$$\left.\begin{aligned} v_j&=\Sigma_n\,[D_n\cos nj\alpha+C_n\sin nj\alpha\,],\\ w_j&=\Sigma_n\,[E_n\cos nj\alpha+F_n\sin nj\alpha\,], \end{aligned}\right\} \qquad (81a)$$

and the coefficients can be obtained from formulæ analogous to (82).

The displacements at the other terminal bulkhead can be similarly expanded and six further constants $\bar{A}_n$, $\bar{B}_n$, $\bar{C}_n$, $\bar{D}_n$, $\bar{E}_n$, $\bar{F}_n$, obtained for each value of n ($0<n<\frac{1}{2}N$) and the three constants $\bar{A}_n$, $\bar{D}_n$, $\bar{E}_n$, for each of the two values $n=0$ or $\frac{1}{2}N$ if N is even.

Evaluation of the Amplitudes for the Type Systems

25. Concentrating on one particular value of n, suppose that F, G, H, K, L, M are the amplitudes (to be determined) for the six type systems associated with $\epsilon=0$ (§ 13), and concentrating further on one type system, *e.g.*, that of amplitude F, suppose that U_F, V_F, W_F are the values of U_n, V_n, W_n at the left end bulkhead and $\bar{U}_F$, $\bar{V}_F$, $\bar{W}_F$ are the values at the right end bulkhead, then

$$\left.\begin{aligned} A_n&=[FU_F+GU_G+HU_H+KU_K+LU_L+MU_M]_n,\\ C_n&=[FV_F+GV_G+HV_H+KV_K+LV_L+MV_M]_n,\\ E_n&=[FW_F+GW_G+HW_H+KW_K+LW_L+MW_M]_n,\\ \bar{A}_n&=[F\bar{U}_F+G\bar{U}_G+H\bar{U}_H+K\bar{U}_K+L\bar{U}_L+M\bar{U}_M]_n,\\ \bar{C}_n&=[F\bar{V}_F+G\bar{V}_G+H\bar{V}_H+K\bar{V}_K+L\bar{V}_L+M\bar{V}_M]_n,\\ \bar{E}_n&=[F\bar{W}_F+G\bar{W}_G+H\bar{W}_H+K\bar{W}_K+L\bar{W}_L+M\bar{W}_M]_n. \end{aligned}\right\} \qquad (83)$$

A set of six simultaneous equations for $[F, G, \ldots, M]_n$ is thus arrived at. Similar sets can be obtained for each value of n ($0 < n < \frac{1}{2}N$) and sets of four simultaneous equations involving A_n, E_n, A_n, E_n on the left hand sides for each of the values $n=0$ and $n=\frac{1}{2}N$ if N is even.

Proceeding in the same way, suppose that F', G', H', K', L', M', are the amplitudes for the other six types, associated with $\epsilon = -\pi/2$, then further sets of six simultaneous equations are obtained for $[F', G', \ldots, M']_n$ in which terms with dashes replace the terms on the right of (83) and B_n, $-D_n$, F_n, B_n, $-D_n$, F_n replace A_n, C_n, E_n, etc., on the left hand sides. When $n=0$ or $n=\frac{1}{2}N$ if N is even, only a quadratic involving D_n and $\bar{D}_n$ on the left hand sides is obtained.

26. If forces are specified instead of displacements, the procedure is similar; the arbitrarily specified forces are expanded and the coefficients obtained, and the corresponding values for R_n, T_n, Z_n (§22) used in place of U_n, V_n, W_n in constructing the equations analogous to (83).

Since the analysis for the two ends is separate, forces can also be specified for one end and displacements for the other.

In any case, having evaluated the amplitudes for all the $6N$ type systems, the *displacements* of all the joints in the structure under the given conditions can be obtained by synthesis, and hence the stresses determined in every member (§8).

Conclusion

27. From the foregoing paragraphs it will be seen that the method of quasi-Fourier analysis is applicable to the general class of tapered frameworks in which the bays are geometrically similar and the elastic properties of the members also vary from bay to bay according to some independent geometric law. It will be recognised that adaptations and useful combinations such as can be effected for the parallel tube with identical bays can be effected also for this general class of tapered tubes. It is unnecessary, therefore, to elaborate the present theme.

Appendix

Complex Roots of the Cubic Equation (35) *for* s

The separation of the real and imaginary parts of U_n, V_n, W_n, in the case of a complex value of s is somewhat more complicated than in the corresponding case for the parallel tube with identical bays,[17] but is probably best effected in the same way—by the use of hyperbolic functions. A method is briefly indicated here.

Types representing the sum and difference of the types associated with λ_1 and λ_2 (see (32) and (68)) can be written in the form

$$\left.\begin{aligned} U_n &= U_\mu (af)^{-\beta} \cosh(\mu\beta+\eta), \\ V_n &= V_\mu (af)^{-\beta} \cosh(\mu\beta+\eta) + V'_\mu (af)^{-\beta} \sinh(\mu\beta+\eta), \\ W_n &= W_\mu (af)^{-\beta} \cosh(\mu\beta+\eta) + W'_\mu (af)^{-\beta} \sinh(\mu\beta+\eta), \end{aligned}\right\} \quad . \quad \text{(i)}$$

where $\eta=0$ and $i\pi/2$, respectively, and the constants are given [*cf.* (34) and (69)] by

$$\begin{aligned} U_\mu (1-\cos\alpha) : V_\mu \sin\alpha : V'_\mu \sin\alpha : c\,(W_\mu + U_\mu \tan\theta) : c\,(W'_\mu + U'_\mu \tan\theta) = \\ -2a^3f^2\,(k_1\cos n\alpha + 1)\,(1+\cosh 2\mu) \\ +2af\cosh\mu\,[a\,(a^2f^2+1)\,(k_1+1)\cos n\alpha \\ +(k_1+\cos n\alpha)\,\{a^4f^2+1+2a^2f^2k_2\,(1-\cos n\alpha)\}\,] \\ -(a^2f^2+1)\,(k_1+1)\,\{a^4f^2+1+2a^2f^2k_2\,(1-\cos n\alpha)\} + a^2f^2\,(a+1)^2\,(1-\cos^2 n\alpha) \\ : -af\sin n\alpha\,[2a^2fk_1\,(1+\cosh 2\mu) - 2a\cosh\mu\,\{(a^2f^2+1)\,(k_1+1) \\ -2af^2k_2\,(k_1+\cos n\alpha)\} - 2afk_2\,(a^2f^2+1)\,(k_1+1) \\ +af\,(a+1)^2\cos n\alpha - (a^3f^2-1)\,(a-1)\cosh\mu\,] \end{aligned}$$

[17] See R. and M. 1528, Appendix I.

$$
\begin{aligned}
&: af \sin n\alpha\,(a^3f^2-1)\,(a+1)\,\sinh\mu \\
&: -(a^3f^2-1)\,\{-2a^2f\cos n\alpha\,\cosh\mu+a^4f^2+1+2a^2f^2k_2\,(1-\cos n\alpha)\} \\
&\quad -af\,(a-1)\,[a^2f\,(1+\cosh 2\mu)+\{2a^2f^2k_2\,(1-\cos n\alpha)-(a^4f^2+1)\cos n\alpha\}\,\cosh\mu] \\
&: af\,(a+1)\,[a^2f\,\sinh 2\mu+\{2a^2f^2k_2\,(1-\cos n\alpha)-(a^4f^2+1)\cos n\alpha\}\,\sinh\mu].
\end{aligned}
\qquad \text{(ii)}
$$

Suppose that s is complex, then

$$
\left.
\begin{aligned}
s=s_R+is_I&=\cosh\mu=\cosh\,(\mu_R+i\mu_I), \\
\text{and}\qquad \sqrt{(s^2-1)}=\sigma_R+i\sigma_I&=\sinh\mu=\sinh\,(\mu_R+i\mu_I),
\end{aligned}
\right\} \qquad \text{(iii)}
$$

where

$$
\left.
\begin{aligned}
\sigma_R&=\sqrt{\left[\tfrac{1}{2}\{(s_R^2-s_I^2-1)+\sqrt{[(s_R^2-s_I^2-1)^2+4s_R^2s_I^2]}\}\right]}, \\
\sigma_I&=\sqrt{\left[\tfrac{1}{2}\{-(s_R^2-s_I^2-1)+\sqrt{[(s_R^2-s_I^2-1)^2+4s_R^2s_I^2]}\}\right]},
\end{aligned}
\right\} \qquad \text{(iv)}
$$

from which it can be shown that

$$
\left.
\begin{aligned}
e^{\mu_R}&=\sqrt{(s_R+\sigma_R)}\,/\sqrt{(s_R-\sigma_R)}, \\
\text{and}\qquad \tan^{-1}\mu_I&=s_I/\sigma_R.
\end{aligned}
\right\} \qquad \text{(v)}
$$

From a knowledge of the two quantities in (v) it is possible, for any value of β, to separate the real and imaginary parts of

$$
\left.
\begin{aligned}
\cosh\mu\beta&=\cosh\mu_R\beta\cos\mu_I\beta+i\sinh\mu_R\beta\sin\mu_I\beta, \\
\sinh\mu\beta&=\sinh\mu_R\beta\cos\mu_I\beta+i\cosh\mu_R\beta\sin\mu_I\beta,
\end{aligned}
\right\} \qquad \text{(vi)}
$$

and also to separate the real and imaginary parts of the constants U_μ, V_μ, V'_μ, W_μ, W'_μ, given by (ii). It is then possible to separate the real and imaginary parts in the products such as $U_\mu\cosh\mu\beta$.

The condition $\eta=0$ thus provides four type systems, since the real part can be associated with either of the two values for ϵ (§13) and similarly the imaginary part. The condition $\eta=i\pi/2$ provides four further types.

THE ROYAL AERONAUTICAL SOCIETY

With which is incorporated The Institution of Aeronautical Engineers

SIXTY-NINTH ANNUAL REPORT OF THE COUNCIL, 1933—34

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Membership

The membership of the Society must be considered, in view of the general situation, to be highly satisfactory. The following table gives the membership in detail for 1933, and the figures in brackets those corresponding to 1932. There has been an increase in total membership of 42, where a decrease might have been expected. In 1932 there was a decrease of 25, and the fact that there has been an increase in 1933 is a sign of the high standing of the Society. The increase has been most noticeable in the Studentship class and Associate Fellowship class.

	No. of Members.	Hon. & Life Members.	Suspended.	Total.
Fellows	133 (135)	22 (20)	1 (4)	156 (159)
Members	51 (56)	—	2 (3)	53 (59)
Associate Fellows ...	428 (413)	5 (5)	17 (16)	450 (434)
Associate Members ...	89 (88)	—	14 (9)	103 (97)
Associates	166 (166)	3 (3)	15 (15)	184 (184)
Companions	100 (98)	10 (11)	7 (3)	117 (112)
Founder Members ...	24 (25)	1 (1)	— (2)	25 (28)
Students	302 (271)	—	24 (27)	326 (298)
Temp. Hon. Members ...	—	20 (18)	—	20 (18)
	1293 (1252)	61 (58)	80 (79)	1434 (1389)
Less Joint Members ...	27 (28)			
	1266 (1224)	61 (58)	80 (79)	1434 (1389)

Donations

The Council have again to thank the Air Ministry, for the ninth year in succession, for their generous donation of £250 to the funds of the Society, the Society of British Aircraft Constructors for the ninth year in succession for their generous donation of £250 and the Society of Motor Manufacturers and Traders for a donation of £105. More than ever these grants have proved of vital necessity to the welfare of the Society and without them it would have been impossible for the Society to have reached the position it has or to have carried out much of the work it has done during the past few years.

Endowment Fund

The table below gives the progress of the Endowment Fund:—

	£	s.	d.
December, 1926	575	0	0
December, 1927	597	2	0
December, 1928	1,047	18	0
December, 1929	1,077	6	0
December, 1930	1,265	10	0
December, 1931	1,935	10	0
December, 1932	2,196	2	0
December, 1933	9,716	19	5

It will be noticed that there is a very considerable increase in the fund at the end of 1933. In the past year the Council have made arrangements for the Endowment Fund to be made a trust fund and have transferred to it the greater part of the investments in Aerial Science, Ltd. Under the terms of the Trust Fund the amount which is accruing may only be spent with the specific object of providing the Society with its own building and lecture theatre.

The Council have consistently aimed at raising a fund of the order of £50,000 and have taken every opportunity to add to it. Such a fund would not

only enable the Society to have its own premises, but would give it a sum in hand which would allow it to be independent of fluctuations of membership. It would thereby be of very real value to members, and the Council continue to urge upon every member to bear the fund in mind and take every opportunity to add to it.

Library

For the tenth year in succession the Council have to thank Mr. J. E. Hodgson, the Honorary Librarian, for the time he has given to the Library and the expert advice which he has given from time to time. Mr. Hodgson has also continued to act as the representative of the Society at Council meetings of the National Central Library for Students and the Association of Special Libraries and Information Bureaux.

The collections of the Society's slides and photographs are being added to regularly and systematically. The Society has now a collection of over 3,000 slides and a corresponding number of photographs indexed and mounted on sheets. The aim of the Council has been to bring these collections up to date and to fill in the historical gaps as far as possible so that a complete record of the history of aviation, as far as possible, may be collected under one roof. The willing help of members and firms has enabled the Council to go far to achieve their object.

The Council would again like to suggest to members who have slides or photographs or other aeronautical items of interest which they find any difficulty in storing to look upon the Society as a suitable repository, to adopt the attitude of letting the Society have them on permanent loan. At the Society's offices they are readily available for the member when he wishes to use them, and he will be rendering invaluable service by making them available to other members.

Many foreign firms and governments have offered to co-operate to help the Society and already several hundred photographs of aircraft have been forwarded to the Society from the Continent and America. The Council particularly wish to thank them for their very real help and also all those British firms who have forwarded photographs and slides to keep the collections up to date. Without such help it would have been impossible to have obtained so much material as is now available.

The Technical Index which was begun a few years ago has become increasingly useful each year, and is now a most valuable aid to members, who are constantly consulting it. The object of the Council, to induce anyone who wishes to obtain any information about aviation, to apply in the first place to the Society, is rapidly being achieved.

During the year the Society has acted as publishers for the Society of British Aircraft Constructors of an International Index which, it is hoped, will be the first of a series of volumes enabling members to readily find information on any particular side of aviation.

The experiment of opening the Library on Saturday afternoons is being continued and an increasing use is being made of the privilege. The Library is closed on periodical Wednesday afternoons for the meeting of the Council of the Society of British Aircraft Constructors, who have paid all the expenses of keeping the Library open on Saturday afternoons.

Wilbur Wright Memorial Lecture

The Wilbur Wright Memorial Lecture for 1933 was delivered before a distinguished audience on May 30th, 1933, by Colonel F. P. Lahm, Air Corps, U.S. Army, entitled "Training the Airplane Pilot." The lecture was followed by the Annual Council Dinner. Before the lecture was given the various medals and

prizes which have been awarded during the year were presented. The report of the lecture and the Annual Council Dinner appeared in the November, 1933, issue of the Journal.

Lecture Programme

A full list of lectures delivered before the Society, and the principal lectures delivered before the Branches, was given in the Journal for December, 1933. In addition, the following lectures have been delivered or arranged for during the remainder of the present Session:—

January 18th.—Mr. F. Rodwell Banks, O.B.E., F.R.Ae.S., "Ethyl."
February 1st.—Mr. J. D. North, F.R.Ae.S., "Engine Cowlings."
March 1st.—Major F. M. Green, O.B.E., F.R.Ae.S., "Speed and the Economics of Air Transport."
March 6th.—Mr. G. D. Boerlage, M.E., and Dr. W. J. D. van Dyck, "The Relation of the Molecular Structure of Fuels to their Behaviour in Diesel Engines." (Joint meeting with the Inst. of Aut. Engs. and other bodies.)
March 15th.—Mr. H. J. Pollard, Wh. Ex., A.F.R.Ae.S., "Some Developments in Aircraft Construction."
April 5th.—Captain A. G. Forsyth, "Engines."
April 12th.—Mons. Louis Breguet, "Speed and the Future of Commercial Aircraft."
April 19th.—Air Commodore P. F. M. Fellowes, "The Houston-Mount Everest Flight."
April 26th.—Dr. Rud. Stussel, "Landing in Fog."

Lectures before the Branches.

January 2nd (Bristol Branch).—"Testing of Aero Engines," by Mr. G. O. Anderson, A.M.I.Ae.E.
January 4th (Yeovil Branch).—"The R.A.F. Long Distance Flight, 1933," by Flt. Lt. G. E. Nicholetts.
January 9th (Manchester Branch).—"Compression Ignition Engines," by a Member of the Staff of Armstrong-Siddeley Motors, Ltd.
January 11th (Gloucester Branch).—"Slots, Interceptors, etc.," by Mr. Handley Page, C.B.E., F.R.Ae.S.
January 18th (Yeovil Branch).—"Aluminium and its Alloys," by G. H. Field.
January 23rd (Bristol Branch).—"Meteorology," by Captain F. Entwistle, B.Sc.
February 1st (Yeovil Branch).—"Principles of Flight," by Captain G. T. R. Hill.
February 6th (Gloucester Branch).—Lecture by Mr. W. C. Devereux, A.F.R.Ae.S.
February 13th (Bristol Branch).—"New Methods of Testing by Impact," by Prof. R. V. Southwell, F.R.Ae.S.
February 21st (Manchester Branch).—"Flying Travel," by a Member of the Staff of Imperial Airways.
February 23rd (Gloucester Branch).—"Soaring Flight," by Mr. C. H. Latimer Needham, F.R.Ae.S.
February 27th (Bristol Branch).—"Record Breaking Engines," by Mr. R. N. Dorey.
March 1st (Yeovil Branch).—"The Compressed Air Wind Tunnel," by Mr. E. F. Relf, F.R.Ae.S.
March 8th (Gloucester Branch).—"Tubes," by Mr. W. Hackett, M.I.Ae.E.
April 5th (Gloucester Branch).—"Engine Development," by Mr. A. H. R. Fedden, F.R.Ae.S.

Students' Section

The number of students of the Society showed a substantial increase in 1933 over the previous year and there has been a corresponding increase in the activities of the section. In particular the Students' Section have put forward suggestions for enabling students of the Society to obtain greater facilities for flying and these suggestions are now being examined by a Committee of the Council. The Students' Section is one of the most important sections of the Society, for ultimately it is from the students that the technical membership of the Society is largely recruited. The Council watch with real interest the activities of the section, particularly those activities which lead to increasing their knowledge of aviation. Mr. M. Langley, Member of Council, has been specially appointed to keep in touch with the section and act as their spokesman on the Council on any matters appertaining to students.

The Council wish to thank those members of the Society who have acted as chairman at the various students' lectures and firms who have co-operated to make the visits of students to their works ones of interest and value.

In November, 1933, Mr. G. L. H. Bott was appointed Secretary of the Students' Section, and a new committee was appointed.

In addition to the lectures announced in the December, 1933, Journal the following have been given, or arranged for, before the Students' Section:—

November 28th.—An Informal Supper.

December 5th.—Debate, "That Airships are not a Commercial Success."

January 16th.—"Aerodromes in England," by Mr. G. H. Mansell. Chairman: Mr. H. N. St. V. Norman.

January 30th.—"The Covering of Aircraft Wings and Hulls," by E. C. A. Backhaus. Chairman: Mr. F. A. Foord.

February 13th.—"Notes on the Stability of Aeroplanes," by Mr. R. J. Schmidt, B.Sc., Ph.D. Chairman: Dr. H. F. Winny, B.Sc., Ph.D.

Visits.

December 9th.—To de Havilland Aircraft Company.

February 10th.—To Messrs. Handley Page's.

Public Schools' Lectures

For the third year in succession lectures have been arranged before the Public Schools and other educational centres. As a result of the delivery of these lectures there has been an increasing demand for further lectures outside and for the borrowing of slides by members for lecture purposes. Over 250 lectures have been delivered up to date to audiences totalling some 50,000.

The Council wish to record their grateful thanks to all who have helped to make the lecture programme a success. It is work of primary importance and its results may be seen in the increasing interest which is being taken by the schools in aviation and the increasing number of inquiries about the prospects of a career in aeronautics. The Council urge upon all members who can to give one of these standard lectures. There are three such lectures at present and others are in preparation, complete with slides.

In addition to the list published in the December Journal, the following have been arranged for, or delivered, in 1934:—

January 16th.—Northampton Town and County School, Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

January 17th.—Woolwich Polytechnic Engineering Society, Mr. R. A. Wilmshurst.

January 29th.—Nottingham High School, Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

February 1st.—Frensham Heights School, F.O. R. E. G. Brittain.

February 1st.—Porlock Institute, Mr. C. T. Holmes.

February 2nd.—Finchley Branch of Toc H, Mr. W. E. Gray.

February 5th.—Royal Grammar School, Worcester, Mr. F. Radcliffe, A.F.R.Ae.S.

February 5th.—Manchester Society, Mr. T. Hampson.

February 6th.—Rossall School, Fleetwood, Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

February 10th.—Highgate School, Mr. W. O. Manning, F.R.Ae.S.

February 12th.—St. Olave's School, Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

February 12th.—Royal Liberty School, Mr. H. B. Walker.

February 15th.—Blackheath High School, Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

February 16th.—Leeds Grammar School, York, Mr. G. C. F. Ely.

February 17th.—St. Peter's School, York, Mr. G. C. F. Ely.

February 18th.—A Boys' Club, Flt. Lieut. N. Comper.

February 23rd.—Leeds, Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

February 24th.—Hurstpierpoint College, Sussex, Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

March 6th.—Epsom College, Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

March 10th.—Eastbourne College, Mr. S. Scott Hall, A.F.R.Ae.S.

Branches

The year 1933, as with 1932, has been a difficult one for the Branches, but there is shown an increase generally in membership and lectures. The Council realise that the chairman, committees and secretaries of the various Branches, both in this country and in Canada and Australia, have done work of the greatest value during the year, in arranging lectures and keeping up an interest in aviation during a time when great difficulties have had to be encountered and overcome. The list of lectures read before the Branches is an eloquent testimony of the energy and enthusiasm of all those connected with the Branches. The Council urge upon everyone to support their Branches to the fullest possible extent, especially during periods of stress.

The following is a list of Branches and their addresses:—

Bristol.—Hon. Secretary: C. W. Tinson, F.R.Ae.S., M.I.Ae.E., Beaufort House, Southmead Road, Filton, Bristol.

Coventry.—Hon. Secretary: F. Meadows, A.F.R.Ae.S., "Llangstone," Jobs Lane, Coventry.

Gloucester and Cheltenham.—Hon. Secretary: Mr. F. B. Ford, c/o The Gloster Aircraft, nr. Hucclecote, Glos.

Hull and Leeds.—Hon. Secretary: G. B. Fenton, A.F.R.Ae.S., 37, Lonsdale Street, Anlaby Road, Hull.

Manchester.—Hon. Secretary: T. Hampson, 111, Grasmere Avenue, Monton, Eccles, Manchester.

Yeovil.—Hon. Secretary: V. S. Gaunt, Esq., A.M.I.Ae.E., Westland Aircraft Works, Yeovil.

Australia.—Hon. Secretary: J. V. Connolly, A.R.Ae.S.I., Science House, Gloucester and Essex Streets, Sydney, Australia.

Montreal Aeronautical Section.—Hon. Secretary: 2050, Mansfield Street, Montreal.

Ottawa Aeronautical Section.—Hon. Secretary: Sq. Ldr. A. Ferrier, A.F.R.Ae.S., Dept. of National Defence, Slater Street, Ottawa.

Cambridge University Aeronautical Society (Affiliated).—Hon. Secretary: ————, Scoope House, Cambridge.

President

At the meeting of Council held on 9th May, 1933, Mr. C. R. Fairey, M.B.E., F.R.Ae.S., was unanimously elected President for a fourth year of office, October 1933-September 1934.

Mr. Fairey's terms of office have coincided with four very difficult years in the history of the Society. During those years the President has been called upon to help in many ways strictly outside the functions of a President, financially and otherwise, and it is largely through the help which he has so willingly and ungrudgingly given that the Society has maintained its position. He has personally carried out successful negotiations on behalf of the Society with other bodies, and maintained the Society's point of view in many important ways.

Much of the satisfactory state of the Society's finances is due to the help which has been given by the President during his years of office. During the past four years Mr. Fairey has met the deficits on most of the dinners and entertainments given by the Society, notably the heavy deficit on the Wilbur Wright Lectures and Conversaziones, and has entertained, on behalf of the Society, every foreign lecturer during his period of office.

During the year the President founded two new medals, following a suggestion from the then Minister of State for Air, Lord Amulree. These two medals, known as the British Gold Medal for Aeronautics and the British Silver Medal for Aeronautics, are awarded on the advice of a committee which includes Lord Amulree, the Chairman of the Royal Aero Club, and the President and certain Members of Council. The expense of founding the two medals was one which was beyond the Society to meet, and the whole of the cost of striking the necessary dies and making the medals already awarded has been paid by Mr. Fairey.

The Council wish expressly to record their grateful thanks and deep appreciation of the help the President has given in so many ways to the Society.

Journal

The revenue from outside sales of the Journal has been maintained in 1933. The advertisement revenue has decreased, due to the general lack of advertising during the year. The Council hope that all those members of the industry who are members of the Society, will look upon the Journal as an advertising medium whenever possible. It is one of the ways in which the Society can best be helped to lessen the annual deficit.

In 1933 the form of the Journal was altered so that when bound it forms a complete and continuous annual volume, so bringing it into line with the journals of other scientific and engineering societies.

Finance

The Balance Sheets and Income and Expenditure Accounts of Aerial Science, Ltd., and of Aeronautical Trusts, Ltd., are published in this issue of the Journal. The form in which the accounts are drawn up show an excess of income over expenditure of £611 15s. 9d. This excess is entirely due to the donations which have been received and profits on the sale of investments. Deducting the donations, which are year by year grants, and cannot be looked upon as permanent,

(*Continued on page 304.*)

AERONAUTICAL

Balance Sheet,

	£ s. d.	£ s. d.	£ s. d.
Share Capital—			
Authorised—40 Shares of 1/- ach	... ...	2 0 0	
Issued—21 Shares of 1/- each	... ...	1 1 0	
Less—Calls in arrear	... ...	1 1 0	
Pilcher Memorial Fund—			
Capital Account—			
As at 31st December, 1932		99 14 0	
Income Account—			
Balance at 31st December, 1932	28 2 4		
Add Surplus of Income over Expenditure for year to date	4 0 8	32 3 0	
			131 17 0
Usborne Memorial Fund—			
Capital Account—			
As at 31st December, 1932		109 2 5	
Income Account—			
Balance at 31st December, 1932	25 14 0		
Add Surplus of Income over Expenditure for year to date	3 19 0	29 13 0	
			138 15 5
Herbert Akroyd Stuart Fund—			
Capital Account—			
As at 31st December, 1932		688 19 0	
Income Account—			
Balance at 31st December, 1932	109 7 7		
Add Surplus of Income over Expenditure for year to date	23 18 0	133 5 7	
			822 4 7
R.38 Memorial Fund—			
Capital Account—			
As at 31st December, 1932		978 3 10	
Income Account—			
Balance at 31st December, 1932	248 16 6		
Add Surplus of Income over Expenditure for year to date	26 3 10	275 0 4	
			1253 4 2
Edward Busk Memorial Fund—			
Capital Account—			
As at 31st December, 1932		449 6 1	
Income Account—			
Balance at 31st December, 1932	73 16 4		
Add Surplus of Income over Expenditure for year to date	17 5 10	91 2 2	
			540 8 3
Wilbur Wright Memorial Fund—			
Capital Account—			
As at 31st December, 1932		1298 9 9	
Income Account—			
Balance at 31st December, 1932	88 10 5		
Add Surplus of Income over Expenditure for year to date	3 3 0	91 13 5	
			1390 3 2
Simms Gold Medal Fund—			
Capital Account—			
As at 31st December, 1932		250 0 0	
Less—Income Account Deficiency at 31st December, 1932	14 3 6		
Less—Surplus of Expenditure over Income for year to date	12 1 6	2 2 0	
			247 18 0
Royal Aeronautical Society Endowment Fund—			
Capital Account—			
Transfer from Aerial Science, Limited, as per Trust Deed dated 29th December, 1933		9716 19 5	
Less—Reserve for Legal Expenses		50 0 0	
			9666 19 5
			£14191 10 0

We report to the Members of Aeronautical Trusts, Ltd., that we have examined the above explanations we have required. We are of opinion that the Balance Sheet is properly drawn up December, 1933, according to the best of our information and the explanations given to us and as

3, Frederick's Place, Old Jewry, London, E.C.2.
20th February, 1934.

TRUSTS, LTD.

31st December, 1933.

	£ s. d.	£ s. d.
Pilcher Memorial Fund—		
£115 6s. 10d. 3½ % War Loan at cost	116 5 0	
Cash at Bank	15 12 0	
		131 17 0
Usborne Memorial Fund—		
£113 3½ % War Loan at cost	114 11 1	
Cash at Bank	24 4 4	
		138 15 5
Herbert Akroyd Stuart Fund—		
£683 1s. 0d. 3½ % War Loan at cost	698 19 0	
Cash at Bank	123 5 7	
		822 4 7
R.38 Memorial Fund—		
£1048 11s. 2d. 3½ % War Loan at cost	1098 18 10	
Cash at Bank	164 15 4	
	1263 14 2	
Less—Amount owing for 1933 Award	10 10 0	
		1253 4 2
Edward Busk Memorial Fund—		
£284 4s. 2d. 3½ % War Loan at cost	284 4 2	
£217 London Transport 4½ % "A" Stock at cost	200 1 11	
	484 6 1	
Cash at Bank	56 2 2	
		540 8 3
Wilbur Wright Memorial Fund—		
£1047 6s. 7d. 3½ % Conversion Stock, at cost	800 0 0	
£550 Canada 4 % Stock, at cost	531 10 9	
	1331 10 9	
Cash at Bank	91 13 5	
	1423 4 2	
Less—Amount owing to Aerial Science, Ltd.	33 1 0	
		1390 3
Simms Gold Medal Fund—		
£287 16s. 1d. India 4½ % Stock, 1958/68, at cost	250 0 0	
Cash at Bank	32 5 6	
	282 5 6	
Less—Amount owing to Aerial Science, Ltd.	34 7 6	
		247 18 0
Royal Aeronautical Society Endowment Fund—		
Investments at Cost—		
£2043 19s. 8d. 3½ % Conversion Stock	1584 18 3	
£293 18s. 3d. 4 % Treasury Bonds, 1934/1936	295 2 10	
£1192 13s. 0d. 3 % Local Loans	1034 15 5	
£4100 L. & N.E. Rly. 3 % Debentures	3162 6 3	
£3100 L.M. & S. Rly. 4 % Debentures	3162 19 9	
	9240 2 6	
Cash at Bank	316 0 11	
Amount due from Aerial Science, Limited	160 16 0	
	9716 19 5	
Less—Reserve for Legal Expenses	50 0 0	
		9666 19 5
		£14191 10 0

Balance Sheet with the books of the Company and have obtained all the information and so as to exhibit a true and correct view of the state of the Company's affairs as at 31st shown by the books of the Company.

PRICE, WATERHOUSE & CO.

AERIAL SCIENCE, LIMITED

Balance Sheet.

	£ s. d.	£ s. d.
Share Capital—		
Authorised—		
20 Shares of 1/- each	1 0 0	
999 Shares of £1 each	999 0 0	
	1000 0 0	
Issued—		
19 Shares of 1/- each		0 19 0
Sundry Creditors		434 9 1
Bank Overdraft		147 13 5
Subscriptions Received in Advance		206 8 0
Endowment Fund—		
Balance at 31st December, 1932	2196 2 0	
Add—Donations received during year	3 2 0	
Entrance Fees received during year	157 14 0	
Transfer from Surplus	7360 1 5	
	9716 19 5	
Less—Transfer to Aeronautical Trusts, Limited, as per Trust Deed dated 29th December, 1933	9716 19 5	
Surplus—		
Reserve Fund at 31st December, 1932	3553 0 9	
Income and Expenditure Account—Balance at 31st December, 1932	5097 14 10	
	8650 15 7	
Less—Transfer to Endowment Fund	7360 1 5	
	1290 14 2	
Add—Surplus of Income over Expenditure for the year to date ...	611 15 9	
		1902 9 11
		£2691 19 5

We report to the Members that we have examined the above Balance Sheet with the Books are of opinion that such Balance Sheet is properly drawn up so as to exhibit a true and correct information and the explanations given to us and as shown by the Books of the Society.

8, Frederick's Place, Old Jewry, London, E.C.2.
19th February, 1934.

Income and Expenditure Account

Dr.	£ s. d.
To Office Rent, Heating, Lighting and Insurance	572 7 8
,, Salaries	1127 18 5
,, Printing and Stationery	259 10 11
,, Postages, &c....	138 10 8
,, Office Expenses	429 1 7
,, Meetings	145 8 9
,, Journals and Pamphlets (*Less* Sales)	928 13 3
,, Library Expenses	39 4 4
,, Audit Fee	29 8 0
,, Prizes and Donations	23 15 0
,, Cost of Badges (*Less Sales*)	0 1 3
,, Examination Expenses (*Less Fees*)	6 15 0
,, School Lectures	38 15 11
,, Subscriptions Written off	90 15 0
,, Surplus of Income over Expenditure for Year, carried to Balance Sheet	611 15 9
	£4442 1 6

(The Royal Aeronautical Society).

31st December, 1933.

	£ s. d.	£ s. d.
Office Furniture, Printed Books, Bindings, Old Prints, etc., at cost, as at 31st December, 1932	450 5 11	
Additions during year—		
Patent Specification Bindings	38 5 0	
Less—Unexpended Balance of Carnegie U.K. Trust Grant	34 11 5	
	3 13 7	453 19 6
Stock of JOURNALS *and other Publications*		497 14 3
Stock of Stationery		13 0 0
Sundry Debtors, including Subscriptions owing		114 8 4
Rent paid in advance		125 0 0
Investments at Cost—		
£1456 0s. 1d. 4% Treasury Bonds 1934/36		1487 17 4
		£2691 19 5

of the Society, and have obtained all the information and explanations we have required. We view of the state of the Society's affairs as at 31st December, 1933, according to the best of our

(Signed) PRICE, WATERHOUSE & CO.

for the Year Ending 31st December, 1933.

Cr.	£ s. d.	£ s. d.
By Annual Subscriptions		3101 8 7
,, Interest on Investments (Including Endowment Fund Investments) (*Less Tax*)	355 8 10	
,, Income Tax Recovered	40 3 1	
,, Bank Interest	0 4 1	
		395 16 0
Profit on Sale of Investments	... ...	294 16 8
,, Donations	... ...	631 5 0
,, Dinners and Receptions	... ...	18 15 3
		£4442 1 6

AERONAUTICAL

INCOME & EXPENDITURE ACCOUNTS

Pilcher

RECEIPTS.

	£ s. d.
To Surplus of Income over Expenditure for year carried to Balance Sheet	4 0 8
	£4 0 8

Usborne

To Surplus of Income over Expenditure for year carried to Balance Sheet	3 19 0
	£3 19 0

Herbert Akroyd

To Surplus of Income over Expenditure for year carried to Balance Sheet	23 18 0
	£23 18 0

R.38

To 1933 Award	10 10 0
,, Surplus of Income over Expenditure for year carried to Balance Sheet	26 3 10
	£36 13 10

Edward Busk

To Surplus of Income over Expenditure for year carried to Balance Sheet	17 5 10
	£17 5 10

Wilbur Wright

To 1933 Award	50 0 0
,, Surplus of Income over Expenditure for year carried to Balance Sheet	3 3 0
	£53 3 0

Simms Gold

To Balance of 1932 Award	0 17 6
,, Surplus of Income over Expenditure for year carried to Balance Sheet	12 1 6
	£12 19 0

TRUSTS, LTD.

FOR THE YEAR ENDED 31ST DECEMBER, 1933.

Memorial Fund

PAYMENTS.

	£ s. d.
By Interest on Investments (gross)	4 0 8
	£4 0 8

Memorial Fund

By Interest on Investments (gross)	3 19 0
	£3 19 0

Stuart Fund

By Interest on Investments (gross)	23 18 0
	£23 18 0

Memorial Fund

By Interest on Investments (gross)	36 13 10
	£36 13 10

Memorial Fund

By Interest on Investments (*less* Tax)...	17 5 10
	£17 5 10

Memorial Fund

By Interest on Investments (*less* Tax)	53 3 0
	£53 3 0

Medal Fund

By Interest on Investments (gross)	12 19 0
	£12 19 0

there is an actual loss on the year of £19 9s. 3d. The actual losses (without donations) in previous years were as follows:—

	£	s.	d.
1932	115	8	5
1931	159	12	11
1930	186	14	2
1929	862	0	0

The loss, it will be seen, is the lowest for five years, a result upon which the Society is to be congratulated.

The annual subscriptions again show a small increase—a most satisfactory sign considering the financial situation generally. During the year the Society's investments were converted into other trustee stock and a sum of £7,360 1s. 5d. was transferred to the Endowment Fund Trust. The accounts, therefore, this year, present a more accurate picture of the Society's position.

There is an increase in the apparent cost of the Journal, due to writing down the value of the stock of Journals. It has been the policy of the Council to write down stock each year, a policy which will be continued until the stock of Journals and other publications stands in the books at a nominal figure only.

Solicitor

Mr. Lawrence A. Wingfield, M.C., D.F.C., A.R.Ae.S.I., has continued to act as Solicitor to the Society, and the Council wish to place on record the valuable services he has rendered. He has advised the Council on a number of important legal questions and has been of considerable help on Committees of Council.

Honorary Treasurer

The Council have had the advantages of the services for the seventh year in succession of Major D. H. Kennedy, F.R.Ae.S., the Honorary Treasurer and Chairman of the Finance Committee. Upon Major Kennedy and the Committee falls the invidious task of conserving the finances of the Society without lessening its activities. Major Kennedy has put forward many suggestions for increasing the income of the Society, and the Council wish to record the debt which they, and all members, owe to Major Kennedy for his untiring energy on behalf of the Society, which is reflected in the increasingly satisfactory balance sheets of the Society during the past few years.

Honorary Accountant

Mr. Norman Smith, the Honorary Accountant, during 1933 completed his sixth year of office. It is due to Mr. Smith that the Society's income is now tax free and that the various investments of the Society have been carried through to a better advantage. The Council wish to record their grateful thanks to him for the time and advice he has so freely given which have resulted in such a lasting benefit to the Society.

Staff

The staff of the Royal Aeronautical Society remains among the smallest staffs of any corresponding society. During the past six years the office work of the Society has increased very rapidly. It is upon the staff that the real work falls, and upon them that the final efficiency of the administration of the Society depends.

During the year the Society lost the services of Miss Jarvis, due to a serious illness. Miss Jarvis, who was the chief assistant to the Institution of Aeronautical Engineers, joined the Society's staff on the amalgamation in 1927 and most ably co-operated in the work she was called upon to do. It was with very great regret that her resignation was accepted by the Council. Her place has been taken by Miss Barwood, who has rejoined the staff of the Society on which she served in the years 1918-1927.

The Council wish to record the very excellent work which has been done by Miss Todd during the year and that of Miss Voyce, both of whom by their constant attention to the affairs of the Society have greatly lessened the work of the Secretary.

The President and Council would like to put on record their profound appreciation of the work of the Secretary, Captain J. Laurence Pritchard, who has not only rendered the greatest service to the Society as in previous years, but has identified himself generously with every movement that appertains to its benefit or prestige.

REVIEWS

Exploring the Upper Atmosphere

By Dorothy Fisk. Published by Faber and Faber. Price 6/-.

Miss Fisk has attacked the task of explaining modern theories about the upper atmosphere in a popular manner. She starts with accounts of the various human ascents by balloon, describes what can be done with sounding balloons, and goes on to explain the deductions which can be made from the phenomena associated with the distribution of the noise caused by explosions, the behaviour of Hertzian waves, and the aurora borealis. It would seem from her account that there is a great deal more to be learnt before a consistent explanation of the various known facts can be attempted. At present it seems that every investigator who wishes to explain the curious behaviour of, say, rays of a certain wave-length, gets over his difficulty by postulating a layer at an appropriate distance above the earth endowed with appropriate properties. After this, all is plain sailing. But it seems to be necessary, in order to account for all such phenomena, to postulate a very large number of such layers so that the upper atmosphere may be considered as somewhat resembling an onion, except that the atmospheric layers seem to vary in thickness and height from day to day for reasons which are not understood.

But, just as things were settling down, it was discovered that if wireless signals of a certain length were generated they sometimes returned to earth after a period which sometimes extended to 30 seconds, which means that the distance travelled by them must have exceeded five and a half million miles. This behaviour seems quite unexplained, though the idea of a further layer at a remote distance from the earth has been invoked as a possible explanation.

Not until a great many more facts have been ascertained will it be possible to take a broad view of the whole subject and to produce a picture of the conditions in the upper atmosphere which will be in accordance with experimental data and which will possess the virtue of consistency.

Miss Fish has done her work very well indeed, and the book should be read by all those who like to be up to date in scientific matters without having to wade through formulæ.

Something New Out of Africa

By H.W. Published by Sir Isaac Pitman and Sons, Ltd. Price 15/-.

H.W. is clearly an officer of the Royal Air Force. In addition to this, he is a keen observer with an interest in antiquities and native customs; he has an eye for a situation which will make a good photograph; he is a humorist; writes good readable English, and has flown over a good deal of Northern Africa. With these qualifications it is not surprising that he has written an excellent book.

The author describes in some detail the various flights he made in Africa, in two of which he had the privilege of piloting the King of the Belgians and the Prince of Wales. He has always something new to say about the native tribes with which he came in contact, many of which had never seen an aeroplane before. This seems to have been especially the case at Bathurst, on the West Coast, where the natives wear clothes resembling European and speak pidgin English. An aeroplane is a "flyboat," and the natives thought it was wound up at the last stop but were astonished to find that "men lib inside."

We are also told something about Abyssinian art, with illustrations. It seems that these people have an artistic convention by which all honest men are represented full face, while a side-face portrait means that the sitter is a knave. The story of King Solomon and the Queen of Sheba, from, presumably, the Queen's point of view, is most entertaining, but it is sufficient to say here that the king is invariably represented side-faced. There is also an appealing story of a little girl who, on leaving Khartoum, wished to say goodbye to the statue of General Gordon, who is represented seated on a camel. "Goodbye darling Gordon, and please say goodbye for me to the funny little man on your back."

There is a good deal on the subject of wild game in Africa, and it is interesting to note that the author does not think game are easily stampeded by aircraft overhead, contrary to impressions given by other travellers. The book contains a magnificent collection of animal photographs taken from the air.

It is possible that the most interesting part of the book, from the technical point of view, is that dealing with seaplanes on the Red Sea, when they undertook the job of stopping and examining native craft for the purpose of ascertaining whether they contained slaves or contraband. A certain amount of trouble occurred from damage to the floats caused by coral reefs, but experience taught how this could be largely avoided. The Author makes it clear how efficient air control of this traffic is, as it is impossible to hide a boat behind an island when there is a seaplane overhead. He is a believer in the large flying boat for work of this type, and there is little doubt from what he says that very few machines would be needed to keep complete control over the sea traffic in this neighbourhood.

The book is especially remarkable for the large number of excellent photographs it contains which illustrate every feature which is dealt with. They range from archæology to wild game and native customs. The book is dedicated, by permission, to the Prince of Wales and has a foreword by Lord Mottistone. It is a work of the greatest possible interest and reflects credit both on the author and the publisher.

Mechanics of Flight

By A. C. Kermode. Published by Sir Isaac Pitman and Sons, Ltd. Price 8/6 net.

This is the second edition of a book which forms one of a series of three volumes dealing with the elements of aeronautical engineering. They are intended to be read as an introduction to the subject, and care has been taken to make the explanations as simple as possible and to use only elementary mathematics.

This particular volume is concerned with aerodynamics as applied to the aeroplane, and Mr. Kermode has been very successful in his object. He has dealt with his subject very thoroughly, and any one who reads his book with ordinary care should have no difficulty in understanding the main outline of the nature of the air forces on an aeroplane in flight. This particular edition differs little from the original, but the larger and clearer type used makes the book much easier to read. There is also an addition in the form of a note giving a short explanation of the flow of air over an aeroplane wing in accordance with modern theory. It is suggested that this subject might be dealt with in much greater detail if a third edition is issued, as it presents much less difficulty to a student than is usually supposed.

The book is well illustrated and the diagrams are numerous and unusually clear; it can be thoroughly recommended to those who are commencing to study applied aerodynamics.

CORRESPONDENCE

To the Editor of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

Sir,—With reference to my recent article on "Rocket Propulsion," and the conclusion indicated that *in air* rockets are much less efficient than aeroplanes on account of the kinetic energy lost in the ejected material, the suggestion has been made in several quarters that this loss might be greatly reduced if air were admitted to the discharge nozzle, where it would add mass to the ejected stream and so reduce the velocity. In actual fact this procedure seems impossible, as, except near the rearmost part of the discharge nozzle, the explosion pressures must be too high to permit of the introduction of appreciable quantities of air.

Yours faithfully,

HERBERT CHATLEY.

January 19th, 1934.

To the Editor of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

Sir,—I have been very interested in the recent accounts of tests of the Thurston "Wing-tip Rotors" which you have published, but I have not noticed any suggestions as to the theory of their action. It occurs to me that the improvement in lift is bound up with the effect first noted by Katzmayr, and named after him (I have not the reference by me, but think his paper was published in the Z.F.M. about five years ago). Katzmayr noted that he got improved polar curves (lift/drag against mean angle of incidence) for model aerofoils when these were subjected to a draught whose direction oscillated periodically up and down through a small angle, instead of remaining constant in direction and magnitude. I believe that the effect of spindle inclination (pp. 148 and 149 of the Journal) and rotor position on the lift could be correlated with the Katzmayr effect.

I should like also to make a mild criticism of the nomenclature adopted for Dr. Thurston's ingenious device. It is, I believe, common in engineering to ascribe the term "rotor" to something cylindrical, or at any rate to a rotating body whose axial length is at least equal to its diameter, *e.g.*, the rotors in electric machines. The Thurston rotors are airscrews in form if not in function. Further, as rotors in the form of long cylinders are being built into experimental wings in Germany, one is inclined to visualise an appliance of similar type in the present case.

Yours, etc.

E. G. RICHARDSON.

February 10th, 1934.

The 572nd Lecture delivered before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

First Meeting, Second Half, 69th Session

The First Meeting of the second half of the 69th Session of the Royal Aeronautical Society was held on Thursday, January 18th, 1934, in the Lecture Hall of the Royal Society of Arts, 18 John Street, Adelphi, W.C.2, at 6.30 p.m. In the chair: Mr. D. R. Pye, F.R.Ae.S., Member of Council, Deputy Director of Scientific Research, Air Ministry.

The Chairman: He had no hesitation in saying that the paper which Mr. Banks had prepared was one of the most important that had been read before the Society for some time, and amply justified, if any justification were needed, the recent election of Mr. Banks as a Fellow of the Society. Mr. Banks was a member of the technical staff of the Ethyl Export Corporation, and as such his business was to persuade everybody to use tetraethyl lead. He (the Chairman) could recommend Mr. Banks' method of doing so to everybody else who had the same kind of job, for what he had done was to state with complete frankness all the troubles which were liable to be met with through the employment of tetraethyl lead in aero engine fuels. He had described in a masterly manner how these troubles had been dealt with, how they might be affected by future engine development, and had suggested means whereby possible future troubles might be overcome. He was able to do this because he was an engineer of wide experience before he took on the job of dealing with the vagaries of ethyl. The speaker recalled that on the first occasion when he had met Mr. Banks, some years ago, he was successfully persuading a certain engine to run at a high speed and higher power output, at considerable risk to his own life, not to mention the lives of others present. The engine ought not in fact to have been running at all. He seemed to remember that when the engine was stopped, at the speaker's own urgent request, most of the main bearings were found to be decorating the crankshaft like a set of elegant bracelets! That would show that Mr. Banks was an engineer of determination, and he had pleasure in calling on him to read his paper.

ETHYL

Some information on the use and advantages gained by the employment of TETRAETHYL LEAD in fuels for aviation engines

BY

F. R. BANKS, O.B.E., F.R.AE.S., M.I.A.E., M.INST.P.T., M.S.A.E.

Part I.

Introduction

This paper is an endeavour to present, to the members of this Society and others, as complete information as possible on the subject of a much discussed anti-knock material and to try and dispel any misconceptions which some may still have regarding the use and behaviour of ethyl.

The development of the modern aviation engine has made rapid strides during the last two or three years. The very rapidity of this development, however, has brought an exceedingly important fact home to the engine manufacturers; this is, the influence of the fuel in governing engine performance and reliability.

Much has been written during the last ten years on the importance of the fuel question, but it is only in the last two years or so that the manufacturers of this country have seriously considered fuel quality with that of engine rating.

Neither the fuel suppliers nor the engine manufacturers can be said to have lagged behind in their respective spheres, but the real cause of the delay in the appreciation of the fuel question seemed to be a lack of understanding of each other's problems between the two sides. If not a lack of understanding, at least the inability of one side to obtain the confidence of the other.

However, this state of affairs does not exist to-day, and the co-operation between the fuel suppliers and the engine manufacturers is in most cases very satisfactory indeed.

Fuel Detonation and Overheating—their Effects

It is naturally assumed that those reading this paper understand the term " detonation," and are conversant with the " physical" and " chemical " theories advanced regarding the causes which make a fuel detonate. The author does not propose to take up time and space in discussing these phenomena, since there are many papers and standard works which deal with them at length.[1] [2] [3]

The fact that any of the fuels available in reasonable and practicable quantities to-day can be made to detonate and/or pre-ignite, under certain conditions, is our chief concern.

There are, of course, many other qualities which a petrol must possess to meet, fully, the specification for a good aviation fuel, but these are relatively easy to ensure with modern refinery methods, and in any case do not come within the scope of this paper.

The particular quality with which we are concerned is generally known as " anti-knock " or " anti-detonation " value.

The anti-knock value of a fuel is a measure of its ability, or otherwise, to resist detonation, and this value is usually assessed in terms of octane number.[4] It may be said, quite truthfully, that the principal limitation of modern engine development is fuel detonation and/or the effect of temperature rise on the engine parts, due to the behaviour of the fuel.

To those not in direct touch with engine and fuel development, these effects will be discussed in order to explain how they limit engine performance.

There is now ample proof to show that, under detonating conditions in the cylinder of an engine, the whole of the fuel does not detonate, but only a portion. Continued detonation is obviously uneconomical and harmful, because it causes overheating troubles.

Unfortunately, in the case of these large engines of high specific power output, audible detonation is not easy to detect, and often is not at all apparent. In fact, in a number of cases, the term " detonation " is not perhaps quite correct. The particular phenomenon experienced with some fuels manifests itself in the form of a dangerous rise in the working temperature of the cylinder. This is particularly noticeable with air-cooled engines, and in many cases, either in air- or water-cooled types, the engine will shut down due to pre-ignition, or definite damage due to overheating, without any sign of audible detonation.

Cases have come to one's notice where engines have suffered from troubles in the form of scored, or, as our friends in America term it, " scuffed " pistons, together with ring sticking and failure. Part of the piston crown and top ring land sometimes having crumbled or burned away.

In some of the cases concerned, this trouble has been attributed to lubrication failure and the oil has been blamed. However, a change to a different class of oil did not cure the trouble.

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[1] " The Internal Combustion Engine," by D. R. Pye.
[2] " The High Speed Internal Combustion Engine," by H. R. Ricardo.
[3] " The Phenomenon of Knocking," by E. S. Taylor, " Aircraft Engineering," June, 1933.
[4] See Appendix I.

Detonation or overheating, due to the fuel, was then suspected as the cause of the trouble and suspicion rested on the fuel, which was changed for one of superior knock rating and no repetition of the trouble then occurred.

Detonation of the fuel is essentially due to a combination of temperature and pressure and the chemical state of the fuel/air mixture when in the cylinders of the engine.

The petrols which are the main constituents of the fuels used to-day, come from many parts of the world, and, according to their sources of supply, all vary in their ability to withstand detonation. The variations are in many cases quite considerable.

Naturally, engines should be designed so as to minimise the chances of detonation, and the position of the sparking plugs, the degree of turbulence of the charge, the temperature of the exhaust valve under operating conditions, and the general cooling of the combustion chamber, must all be carefully considered.

However, engine design is all a compromise, and it is often very difficult to arrange even such essentials as the positions of the sparking plugs so that they can ignite the charge in the most efficient manner.

The combustion chamber design itself must generally be subordinated to other requirements such as low frontal area, which practically demands a low stroke/bore ratio, making the flame travel distance (in the combustion chamber) large for a given clearance volume, and the tendency to detonation greater.

All these points make it harder to obtain high specific power output without running into detonation or over-heating.

The influence of the " anti-knock " value or octane number of the fuel on engine performance is well illustrated by the following authentic example:—A well-known supercharged engine, in this country, which is rated at approximately 500 b.h.p. at an altitude of 11,000 or 12,000 feet, was only capable of developing this power at ground level when using fuel to the Air Ministry's late D.T.D. 134 specification, which had an octane number of 75·5-76.*

With this fuel, and at ground level, the throttle could not be opened beyond the " gate," otherwise destructive detonation occurred.

A change was made to a fuel having an octane number of about 90, under the same conditions of knock rating; this enabled the engine to be operated at full throttle (ground level) and under these conditions it gave nearly double its rated output, *i.e.*, about 900 b.h.p. It is not to be supposed that this particular engine, or any other standard type for that matter, could at this stage be operated indefinitely at such a high rating by making a fuel of the necessary anti-knock value immediately available. Much development would have to be done to obtain reliability and give reasonably long periods of operation between overhauls, but this illustration serves to show that it is necessary to have suitable fuel to enable development to go forward.

For military aircraft, in times of national emergency, such as war, long periods of running between overhauls are not essential, and reliable operation for relatively few hours is all that is required.

Probably 50 engine hours in all would be a maximum. Consequently, with a suitable fuel, modern engines could be run considerably above their present ratings and enable fighters to clip valuable seconds, and even minutes from the normal time taken to reach their operating altitudes. Also, being able to use the full amount of supercharge possible, between ground level and operating altitude, would make such aircraft very formidable to an enemy whose machines may endeavour to create a surprise attack by coming in low down.

Fig. 1 shows two curves plotted from the results obtained from the actual tests of a fast single-seater interceptor fighter with two fuels. (A) with D.T.D. 134 fuel, (B) with D.T.D. 134 plus 4 c.c.'s of tetraethyl lead per gallon. No

* Octane value ascertained on a " Series 30 " engine running at 900 r.p.m. with a jacket temperature of 100°C.

alteration was made otherwise. Fuel (B) allowed full throttle to be used from ground level to operating altitude. The increase in rate of climb from ground level to 10,500 feet, with this fuel, in comparison to fuel (A), is about 38 per cent., and from ground level to 20,000 feet is 16 per cent.

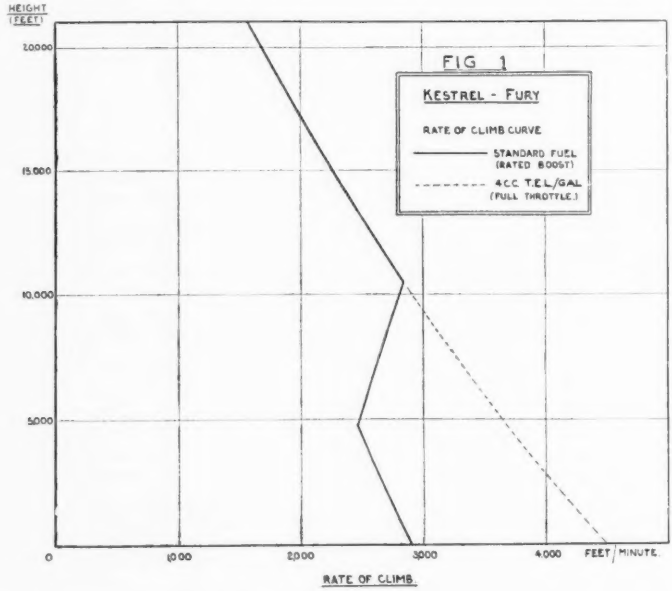


Fig. 2* gives some idea of the relationship between octane number and B.M.E.P. The shaded area, enclosing three curves, gives an indication of what can be done by a good combination of compression ratio and supercharging in order to obtain the most from an engine with fuels of given octane values. The full line represents some tests done on a well-known American air-cooled radial, and the dotted lines have been added by the author from results obtained in this country on well-known British liquid and air-cooled engines.

The shaded area embraces about five octane numbers, and is given to make allowance for the performances of different engines which will, according to their individual design, take more or less advantage of a particular fuel. It is obviously unwise at this stage to set a definite limit on engine performance in connection with octane value.

The curve outside the area shows what has been done with an unsupercharged engine, compression ratio alone being increased. The " dot " on the left hand of the graph gives the maximum B.M.E.P. obtained some years ago on a single-cylinder air-cooled engine employing a relatively low compression ratio and a high degree of boost, or supercharge, at low temperature.

Actually, the *rated* performance of aviation engines at present in service in aircraft, with fuels of given octane values, would produce curves lying somewhere between the curves in the shaded area and the lower curve on the graph.

To obtain increased power from an engine of given cubical capacity there are three courses open to the designer, each or all of which may be employed. These are:—

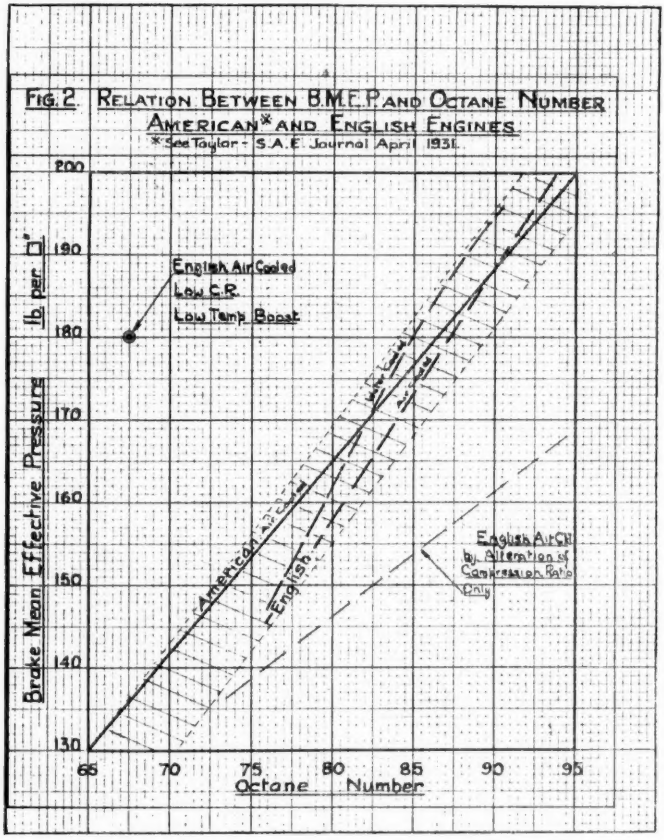
(*a*) Raising the compression ratio.

* American results reproduced from paper by Taylor, S.A.E. Journal, April, 1931.

(*b*) Supercharging.
(*c*) Increasing the crankshaft speed (r.p.m.).

An increase in the compression ratio will improve the power output, lower the specific fuel consumption, and reduce the amount of heat to cooling medium, lowering also the temperature of the gases at exhaust point.

A supercharger, or blower, whether used for filling the cylinders to maintain " ground level " power at altitude or for definitely " boosting " an engine to

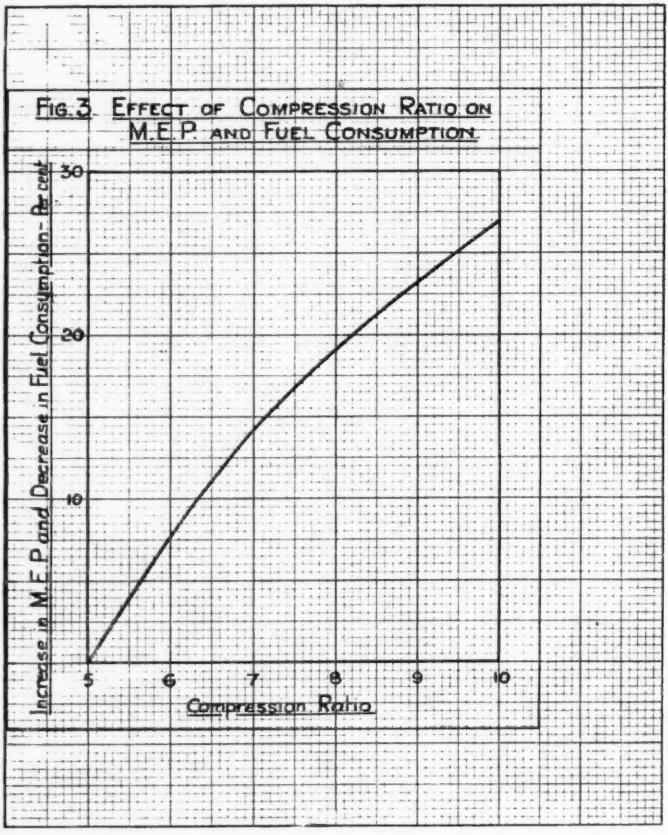


give a higher specific power, is being used more generally and is designed as an integral part of the engine, instead of, as in the past, being regarded as an accessory. It is a very effective and satisfactory method of increasing the b.h.p., provided the blower is efficient in itself and does not absorb excessive power, also, that it is not fitted in an attempt to improve the " efficiency " of a poorly valved engine.

The limitations to high crankshaft speeds are the loadings on the reciprocating parts and bearings, but these, although big difficulties to overcome, are not insuperable, and there is a general tendency to increase operational speeds of modern engines.

These methods of increasing the specific power output impose a heavy duty upon the fuel and may cause detonation and overheating, with their attendant troubles such as pre-ignition, damaged pistons and big ends, and overheated exhaust valves. Exhaust valves will operate at considerably increased temperatures with supercharging.

Fig. 3 gives a curve showing the effect of compression ratio on power and fuel consumption at constant speed. In this connection, one would add that where



a supercharger is fitted and if it is desired to increase the power output further by using a greater degree of supercharge in addition to raising the compression ratio, it would be well to make careful bench tests in order to obtain the most suitable values for each when working in combination.

The Choice of Anti-Knock Materials for Aviation Fuels

There are at the moment two practical anti-knock materials available to the fuel suppliers of this country in order to make up suitable fuels for aviation engines. These are:—

(1) Benzole.
(2) Ethyl fluid (tetraethyl lead).

The alcohols, such as methyl and ethyl, have from time to time been considered and are still engaging the attention of some countries, but in the author's opinion it is not economic to use them, and from a technical point of view there are other objections to their use. They are difficult to blend with petrols unless the former are substantially anhydrous, and their storage is a real problem since the presence of minute percentages of water bring about separation. The calorific values of these alcohols are low in comparison with petrol, and the specific fuel consumption is raised considerably if they are added in excess of, say, 15 to 20 per cent. by volume. Alcohol fuel blends also cause considerable corrosion and solvent troubles with the materials which are used in the construction of aviation engines and their fittings, such as the aluminium alloys used for fuel tanks and carburettor castings, also jointings, etc.

The higher alcohols, such as iso-propyl have been investigated but do not at the moment seem to offer any particular advantages.

(1) *Benzole*

Benzole has been used for some years with success as an anti-knock material. It is a fuel in itself of exceedingly high anti-knock value and does not usually detonate in the ordinary sense but can give rise to severe pre-ignition under appropriate conditions.

Benzole is not generally used by itself, but is blended with petrols. The amount added to any petrol naturally depends upon the anti-knock value of the basic petrol used and the final value required. Quite usual quantities of benzole in such blends may vary between, say, 10 to 30 per cent. by volume or more.

Benzole is a coal tar distillate being composed of hydrocarbons of the aromatic series (benzene, toluene and xylene).

In addition to benzene and toluol derived from coal tar, higher aromatic hydrocarbons such as ethyl-benzene, pseudo-cumene and mesitylene have been synthesised and used, on an experimental scale, as fuel for aviation engines.

Coke ovens in the steel plants are the principal sources of the supply of benzole, the gas companies taking second place. In comparison to the former, the latter do not represent a large proportion of the total production. From the economic aspect, and having in view the development of civil and military aviation in the near future, it appears that adequate supplies of benzole will be difficult to obtain to meet all needs. In fact this situation already exists, and in a number of European countries it is hardly possible, if not impossible, to obtain. In many cases, if obtainable, it is often a very impure product and hardly fit for use.

In the countries which do not have their own coal and steel production, benzole must be imported—at a price!

In the case of war, all the supplies of benzole would undoubtedly be commandeered for the manufacture of explosives. Toluene, particularly, being the basic raw material for the manufacture of T.N.T.

So much for the economics; from the technical point of view there are drawbacks to the use of benzole in aviation fuels. As mentioned before, it is relatively expensive and has to be added in fairly large quantities in order that the resultant fuels may be up to the standards demanded by modern high duty engines.

For peace-time military purposes, while cost is important it is not necessarily the ruling factor where engines must have the correct fuel, but even allowing for this the performance of the modern military aeroplane has been largely responsible for relegating benzole to a secondary position as an anti-knock material in aviation fuels, due to the former's capability of operating at considerable altitudes.

The principal constituent of benzole is benzene. Benzene has a freezing point of about + 5°C. Consequently, to avoid freezing troubles in the fuel system, the amount of benzole which can be added to any petrol must be very much

restricted if aircraft are to operate with safety at altitudes which may vary from 15,000 to 30,000 feet, or in cold climates.

From the point of view of civil aviation, one would again repeat that benzole is relatively expensive and almost impossible to obtain in certain countries.

The satisfactory operation of engines in cold climates is also important for civil work. One of the principal considerations of a civil aviation concern is to be able to obtain adequate supplies of uniform material universally, or at least at points along the particular routes operated by it.

(2) *Ethyl Fluid (Tetraethyl Lead)*

Ethyl fluid is not a fuel, but may be called a chemical knock suppressor. Its basis is, of course, well known and is an organo-metallic compound known as tetraethyl lead.

Previous to its discovery as an anti-detonant, it was regarded, more or less, as a chemical curiosity and was expensive to manufacture.

The history of its development is interesting, and those who desire some information on this are referred to a paper by Tegner on the subject.[5]

Probably nothing in the last twenty years has caused so much controversy as the introduction of tetraethyl lead in the form of ethyl fluid— at least so far as internal combustion engine development is concerned.

Eminent scientists, research workers and others " fell over one another " in their endeavours to show how ethyl could not be used or how great were the difficulties and objections to its use. Despite this, however, its employment becomes more general every year, and after ten years' uphill fight it may be said to have established itself as the most suitable and the most potent anti-knock material so far available.

Ethyl fluid is completely soluble in petrol and will not separate out under any normal storage conditions.

All ethyl fluid is coloured, and that for aviation use is blue. A definite standard of colour is maintained for all blends of fuel containing ethyl fluid.

The fluid is supplied in drums to the oil companies concerned, and, provided that these are kept air-tight, the fluid may be stored almost indefinitely. Its distribution to any blending point in any country is therefore simple.

Due to its potency, the amount added to any petrol is almost minute. Naturally, the concentration will vary according to the basic anti-knock value of the particular petrol and the final value required, which is also controlled by the degree of susceptibility of the petrol itself to tetraethyl lead.

Some idea of the effectiveness of tetraethyl lead may be had when it is stated that the addition of the first cubic centimetre (1.0 c.c.) per gallon (4.545 c.c.'s) to a petrol can raise the anti-knock value of that petrol by anything from 5 to 15 octane numbers, again, of course, depending on the characteristics of the petrol.

A further important point is that the addition of ethyl fluid to any petrol does not affect the latter's characteristics. The specific gravity, distillation range, and, what is more important, freezing point, remain sensibly constant. In fact the fluid has no effect until it reaches the combustion chamber of the engine and the petrol may be regarded as a convenient "carrier" by which it (the fluid) is introduced to and distributed in the cylinders.

Its ease of handling, through standardised blending plants, the convenience of transporting it, and its effectiveness as an anti-knock agent, make ethyl fluid almost ideal for the purposes of military and civil aviation.

The author will go so far as to say that it is the only material in use at the present time which can insure the supply of fuels of uniformly high anti-knock value (octane number) nationally and internationally.

[5] " The History and Development of Anti-Detonating Agents for Motor Fuel," by H. S. Tegner. Proc. Institute of Fuel, April 18th, 1928.

Ethyl Fluid—Its Composition

Tetraethyl lead $Pb(C_2H_5)_4$, has the following characteristics:—

Specific gravity, @ 20°C. = 1.659
Boiling point ... = 200°C. (with decomposition).
Freezing point ... = −156°C.

Ethyl fluid used for aviation purposes is known as " I-T Mix " (blue), and is composed of the following constituents:—

Tetraethyl lead $Pb(C_2H_5)_4$ ... = 61.42% by weight.
Ethylene dibromide ... ... = 35.68% ,, ,,
Dye ... ... = 0.17% ,, ,,
Kerosene and Impurities ... = Balance.
Specific gravity of fluid @ 20°C. = 1.755

Proportion of tetraethyl lead in fluid, by volume, is 65.5 per cent.

Tetraethyl lead, the anti-knock constituent in the fluid, could not be used satisfactorily by itself because the lead oxide, formed during the combustion process in the engine cylinders, would deposit at fairly high rate.

The inclusion of ethylene dibromide was the result of extensive investigation. This halogen bearer converts the lead oxide to lead bromide, which is volatile at the working temperatures prevailing in the cylinder and is evacuated with the exhaust gases in the normal manner.

At first it was difficult to obtain sufficient quantities of bromine for the manufacture of ethylene dibromide, but it has been found possible to recover large quantities from sea water.

The concentration of bromine in sea water is minute, being almost seven thousandths of 1 per cent. By long experimentation, however, it has been possible for the Ethyl Gasoline Corporation to place the recovery of bromine from sea water on a commercial basis. The amount of sea water to be processed is enormous, but since one cubic mile contains approximately 600,000,000 lbs. of bromine, there should not be any shortage in future.

The amount of *tetraethyl lead*, and not *fluid*, is referred to when speaking of concentrations in petrol, since the lead is the active anti-knock agent. The amounts used are so exceedingly small, that confusion is avoided and greater accuracy is ensured when this procedure is adopted.

Subsequent references in this paper will apply to the concentration of tetraethyl lead only, and for the sake of brevity this will generally be designated as " lead."

The maximum allowable concentration of lead in any fuel, for commercial purposes, is 3.6 c.c.'s per imperial gallon (3.0 c.c.'s per U.S. gallon). This is based on a figure of approximately one part in thirteen hundred (1/1,300) of lead in fuel. For Governmental and/or military purposes, the concentration may be increased to 7.0 c.c.'s per imperial gallon (6.0 c.c.'s per U.S. gallon).

Tetraethyl lead is poisonous, and it can be absorbed into the human system through the skin or by the mouth or by inhalation, but the precautions taken in its manufacture and blending with petrol, in special plants, obviate any risks to the operating personnel.

In its diluted state in petrol there is no danger whatever, and fuels containing lead can be handled in the same manner as ordinary petrols.

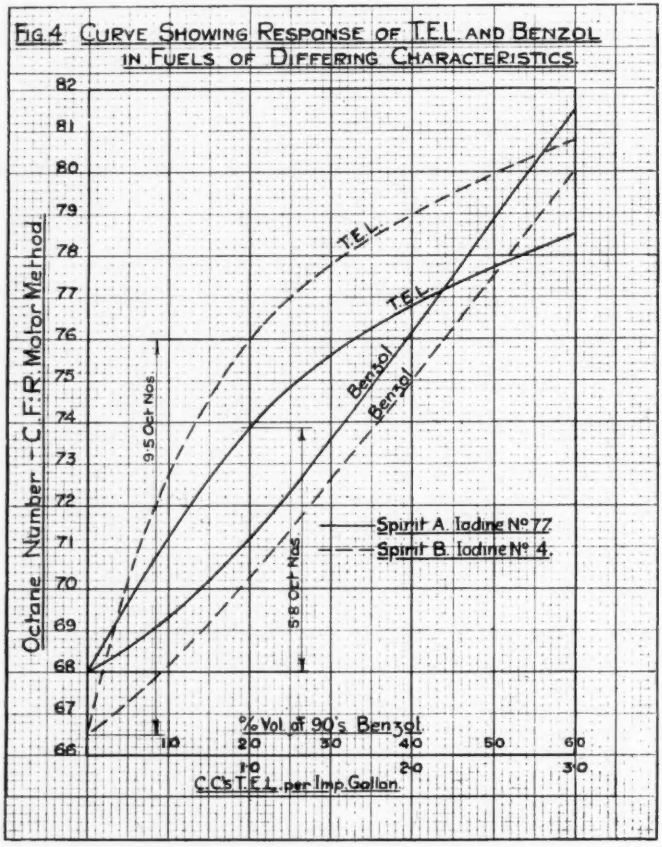
The Effect of Tetraethyl Lead

As previously stated, the addition of lead to a petrol does not sensibly alter its physical, or for that matter its chemical, characteristics, and it has no effect until it reaches the engine cylinders and the combustion process commences.

There are many who think that the lead, in stopping or preventing detonation, " slows up " the combustion process considerably, but from the results of many tests, this does not appear to be the case.

The lead stops or minimises detonation, but it will be found, in practically every test, that it is rarely possible to obtain any benefit by an increase in ignition advance after the elimination of detonation by the use of lead.

This is not to say that " slowing up " of the combustion process does not occur, but it does not appear to be of great magnitude, say, in comparison with benzole.



With high benzole mixtures the temperature of the cylinder head tends to rise, and this feature has been particularly noticeable with air-cooled engines under certain conditions. The exhaust temperature is generally higher under these conditions and often rises if the amount of benzole in the particular blend is further increased.

The use of fuels containing lead does not in general raise the cylinder head or exhaust temperatures, rather the reverse in some cases, but for all practical purposes they remain substantially the same. This naturally assumes that there is no detonation present in either case.

There is one peculiarity regarding the effect of lead upon the anti-knock value of a petrol; it is, that a progressive increase in the lead concentration does

not give a corresponding increase in anti-knock or octane value. Rather, the increase in octane value gets progressively less with increasing lead concentrations.

For instance, the first cubic centimetre of lead added to a gallon of a particular petrol may raise the anti-knock value of that petrol by ten octane numbers, the second cubic centimetre may only give a further increase of five numbers, and the third an increase of two or three, and so on, until no further increase is shown by additional amounts.

In the case of benzole, increasing amounts blended with a petrol usually show progressive improvement in the anti-knock value of the resultant fuel when tested under conditions of moderate temperature or duty. Fig. 4 shows these features up quite clearly and also shows up the difference in susceptibility of two petrols of unlike characteristics, to additions of anti-knock material. One petrol is highly cracked and the other has a naphthenic base.

There is, however, one very important point scored by a fuel containing lead, over a benzole blend. Suppose two such fuels to have similar knock ratings when tested under the following conditions:—A series 30 knock testing unit, running at 600 r.p.m., with a jacket temperature of 100°C. Now suppose the fuels to be retested on the series 30 engine with the speed and jacket temperature increased to 900 r.p.m. and 190°C. respectively; it may be found that the knock rating of the fuel containing lead will drop by, say, 3 or 4 octane numbers (assuming a direct comparison with a primary reference standard of octane/heptane) but the benzole blend will probably have dropped 8 or 10 numbers.

In fact benzole has been supposed, by many, to have an anti-knock value much greater than pure octane itself, whereas its actual and effective value, when blended with petrols and tested under conditions similar to those employed for checking aviation fuels, is about the same, or even less than that of octane. That is to say, its blending value, *i.e.*, its value when amounts up to about 50 per cent. of benzole are blended with petrols, is lower than that determined arithmetically by taking its estimated anti-knock value into account and assessing the contributory value of the proportion added. This is very clearly shown by the data contained in the paper referred to below.[6]

The blending octane value of benzole, under varying conditions of test, has been assessed and is given in Table I.

TABLE I.

Blending Octane value of Benzole under various test conditions, calculated from 50 per cent. concentrations.

Series 30 engine at 600 r.p.m.		C.F.R. Engine, modified Motor Method (I.P.T. Aviation Method) using mixture temp. of 260°F.
212°F.	300°F.	
100	93	95

It is, therefore, rather difficult, if not impossible, to assess the real value of benzole blends or " lead " additions in a fuel unless the conditions under which they will have to perform in normal service are known and can be simulated when the fuel is under test for knock rating.

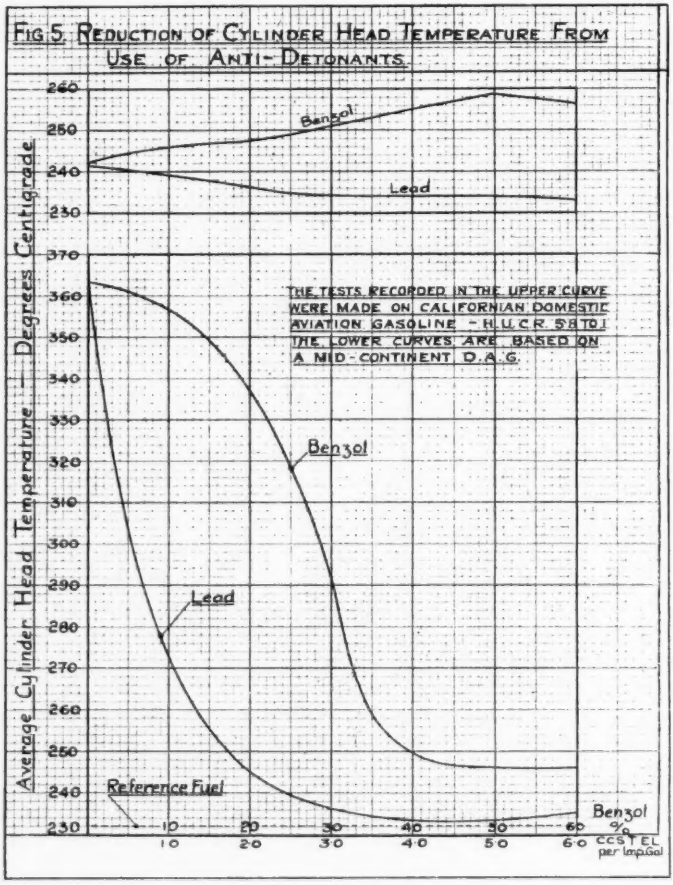
The question of testing fuels for knock rating, and the correlation of these results with the performance of the same fuels under operating conditions in aviation engines, will be discussed at a later stage in this paper.

It is sufficient for the present to say that a leaded fuel, in comparison with a benzole blend, retains its anti-knock value to a high degree when subjected to conditions of high temperature, such as those pertaining, particularly, to air-cooled engines or, for that matter, any high duty engines. The reader is referred

[6] " The Blending Octane Numbers of pure Hydrocarbons and their Dependence upon Concentration," by F. H. Garner, E. B. Evans, C. H. Sprake, W. E. J. Broom. World Petroleum Congress, London, 1933.

to Fig. 5 which shows, graphically, the results of some tests carried out by the Pratt and Whitney firm in America on one of their multi-cylinder air-cooled engines.

The upper set of curves shows, very clearly, the marked tendency of benzole additions to raise the cylinder head temperature, whereas the addition of lead has the opposite effect. The lower curves show the increase of cylinder head tem-



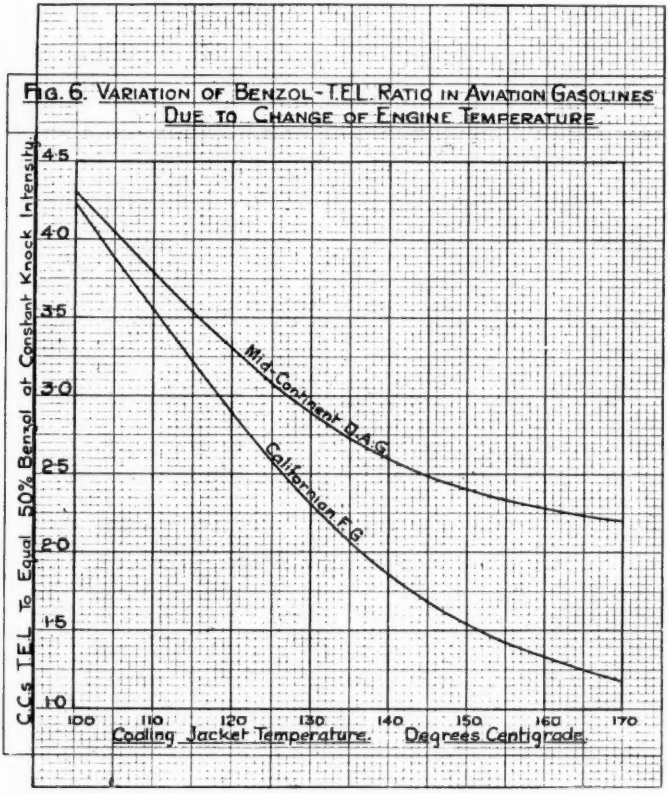
perature, due to detonation, caused by the use of an inferior fuel and the progressive reduction of temperature by adding benzole or lead to eliminate detonation.

The Response of Tetraethyl Lead in Various Fuels

It is not within the scope of this paper to list the hundreds of fuels which have been tested for their lead susceptibility, *i.e.*, their response in anti-knock value to increasing lead concentrations under certain conditions.

There have been many interesting papers published from time to time giving results of these investigations on " straight run " petrols of various basic characteristics, " cracked " petrols, and some of the pure hydrocarbons, etc.

Suffice to say here that all petrols differ in their susceptibility to lead and it is not possible, without a practical test, to estimate the degree by which they will differ or give even a fair approximation of their behaviour with varying amounts of lead. The results also depend upon the particular set of test conditions to which any fuel is subjected.



To illustrate this feature Fig. 6 gives the lead susceptibility curves of two petrols under conditions of varying temperature (jacket). One is a good Californian and one a mid-Continent spirit and both are tested in relation to a benzole blend of 50 per cent. in each fuel.

No doubt many, after reading the foregoing, will be under the impression that the use of benzole or, say, added aromatics in aviation fuels, is to be deprecated. It would, perhaps, be more correct to say that one considers the use of lead, both from a practical and economic standpoint to be more suitable for this purpose. There is no doubt, however, that if fuels of exceedingly high octane values are desired, or where basic fuels of very low values only are obtainable, the use of added aromatics, *in conjunction with that of lead*, will be resorted to, in order to achieve the desired results.

Part II.

Engine Development

Some information indicating the lines to follow in order to make full use of fuels containing lead.

As indicated by the title, the second part of this paper will be devoted to the question of engine development when related to the use of leaded fuels.

In this section it is hoped to clear up the misconceptions still prevalent regarding the behaviour of engines when using this type of fuel.

The manner in which leaded fuels have been viewed, in some quarters, is extraordinary. If the same difficulties had been put in the way of the development of superchargers in this country, one is certain that they would not yet be in use except in a very experimental way and, in consequence, we would not have been in the position to produce some of the world's best aviation engines, as we are doing to-day.

There is now, however, a very real danger of these high standards of performance being raised considerably by our American friends, whose engine development in the past few years has been rapid, and what is more important, has also embraced fairly intensive fuel development at the same time.

With regard to the employment of high octane fuels in America, while a large amount of test bench work was, and still is, being done, they appreciated the necessity of obtaining practical flight experience in the early stages of development and took the view that whatever the results of bench tests, they would probably come up against sundry difficulties in actual service, so the sooner experience was gained the better; particularly with leaded fuels which, they decided, must eventually become generally used. This was five or six years ago!

We in this country, on the other hand, have admittedly obtained valuable data from the test bed during the past two years or so, particularly on leaded fuels, but we shall be left behind if we are not careful, since little data has been obtained on fuels of high octane value and the operation of high duty engines in actual service.

One is prepared to admit that the development of engines in this country, to use high octane value fuels, has of necessity been slow because of the number of obsolescent engines in service, which are difficult to modify suitably, whereas the American engine and fuel developments have grown up together. Nevertheless, while the Air Ministry are well ahead in fuel development when compared with other countries on this side of the water, the fuel to their new specification D.T.D. 230,[7] calling for 87 octane, will not be in active service use until well into next year, whereas the U.S. Army Air Corps have used a fuel of nominally 87 octane for about two years.

Further, the U.S. Army Air Corps have now issued another fuel specification calling for a nominal octane value of 92. The method of test, however, has been considerably altered, so that the numerical value is rather deceptive.

It is the author's opinion that all engine development work should be done with fuels which, to obtain a given octane value, must contain a fairly high concentration of lead in order to get a quick estimation of any difficulties which may manifest themselves in the early stages of development.

The problem of the operation of aviation engines on any fuel, because of their relatively high specific power output, is quite peculiar to their class and cannot be compared with the normal operation of automobile engines with which little or no trouble is now experienced over long periods of use.

This should be borne in mind by those readers who may have a particular interest in the design of automobile engines.

[7] See Appendix II. attached.

Naturally, many points mentioned here will apply to automobile engine design and operation under certain conditions, and it is hoped that such information which does apply will be of help or guidance to those engaged on automobile work.

The aviation engine has to deal *continuously* with a far greater *bulk* of heat per unit volume of cylinder than practically any other petrol engine. It is, therefore, more difficult to obtain reliability over long periods of service without paying greater attention to it between times.

Such items as the pistons and valves are very much larger than those in normal automobile engines and it is therefore more difficult to arrange the design of these parts so that they are able to dispose of the heat satisfactorily and still retain their form and material structure, etc.

No discerning aviation engine designer or experimental engineer will now consider the production and development of an engine without taking the question of fuel quality (anti-knock value) into consideration.

Such is the incentive provided by present day competition that they will generally ascertain whether a suitable fuel, of the highest anti-knock value possible, can be obtained commercially in the areas or parts of the world in which they hope to sell and operate their product, so that they may take full advantage of it in rating their engine.

For military purposes the information regarding the supply of fuel and its anti-knock value is usually known well beforehand.

It is true that the anti-knock value of such a fuel (for military purposes) is not always, in the opinion of the engine manufacturer, sufficiently high to make full use of the capabilities latent in his engine, but it rests with him to show the authorities what he can do with a superior fuel and if he satisfies them they will probably consider the supply of the fuel he requires.

Modern engine development, therefore, demands what may be called at the present time, " super fuels," although in five or ten years these will probably be considered mediocre. That such fuels necessitate the use of lead is now generally recognised.

The Effect of the Products of Combustion of a Leaded Fuel upon the Engine Parts

The main product of the combustion of a leaded fuel with which we are concerned under the above heading is lead bromide.

As previously stated, ethylene dibromide is included in the ethyl fluid in order to convert the lead oxide formed during the combustion process to lead bromide, which is volatile at the working temperatures in the cylinder and most of it is passed out during the normal exhaust stroke.

Under particular circumstances, to be described, the presence of lead bromide may aggravate certain troubles which, previously, might have been latent in the engine, with the possible exception of one, namely, cold corrosion.

The weak links in the chain connecting satisfactory engine performance with leaded fuel are as follows:—

(*a*) The tendency of the exhaust valves to scale and burn, due to " hot " corrosion attack of the valve seat and insert, and/or " mechanical " attack by the pieces of detached scale.

(*b*) " Cold " corrosion attack of the exhaust valve stems, *i.e.*, when the engine is standing idle.

(*c*) " Cold " corrosion of the cylinder bores under the same conditions as in (*b*).

(*d*) Corrosion attack of the exhaust pipes and collector rings.

(*e*) Deposition of lead salts on the sparking plugs.

This list appears formidable, but with the materials available to-day, coupled with suitable design, there is no need for these troubles to persist.

Exhaust Valves and Valve Seat Inserts—General Considerations

The exhaust valve is undoubtedly the most vulnerable part of an engine, because it must perform well at elevated temperatures, *i.e.*, around 800°C., without undue scaling or becoming mechanically weakened and, in addition, remaining gas tight.

In the case of an exhaust valve which works in the presence of leaded fuel, a hard, black, polished and adherent skin generally appears to form on the seat surface in the early stages of running. It is not yet clear whether this skin is a lead product deposited on the seat surface, or is a result of corrosion attack of the seat material itself. One is, however, inclined to the former theory, that it is in the nature of a glaze, since it has also been found on valves which have operated successfully for long periods.

The photomicrographs in Fig. 7 show sections of valve seats with, in one case, the skin referred to and in the others the structure of the material at the seats of damaged and undamaged valves. The valves, from which these sections were cut, are of K.E. 965 material and have run in an engine for about 40 to 50 hours, using a fuel containing 4 c.c.'s of lead per gallon.

The thickness of the glaze or skin varies somewhat and is difficult to assess accurately but, from the photomicrographs, appears to be in the region of 0.0003in. with a thickness of about 0.002in. or more, near the edge of the seat. In cases where the skin has been found on valves which have operated successfully for long periods it is of even thickness with an unbroken surface. In the case of a failure (valve burning), the trouble seems to start when the skin or glaze breaks down. This may be due to a variety of causes; in the first place any irregularities of the seat surfaces of the valve and insert, if the latter are not machined and finished to a high degree of accuracy, will possibly give rise to a skin formation of uneven depth at various points on the valve seat. Cracking and flaking of the skin will then result, causing, in effect, local pitting and finally "guttering." Secondly, due to the high expansion characteristics of austenitic steels and/or the shape of the valve head, the consequent stressing of the skin, due to expansion and contraction of the valve, may cause the former to crack or flake, and in doing so, bring about overheating of the valve because of reduced thermal contact, again giving rise to pitting and burning and also rendering it liable to lead bromide attack.

In this connection one considers that it is very important to experiment and obtain the most satisfactory compromise of valve shape and, also, ensure that the method of forging the valve is correct for the particular class or grade of steel used.

The degree by which the exhaust valve, when in operation, may or may not be attacked by lead bromide is mainly controlled by its working temperature and the material used in its construction.

It is our experience over here, and one believes, in America, that a combination of low working temperatures for the valve with a given material may cause little or no trouble. However, an increase in working temperature may give rise to valve troubles, due to failure of the material to withstand, at the increased temperature, the lead bromide attack, and it will then scale and perhaps burn.

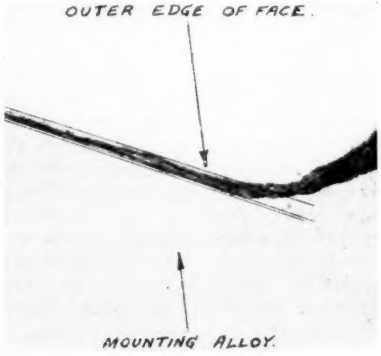
To eliminate these troubles at the outset, the broad principle is to ensure by suitable design that the working temperature of the exhaust valve will be kept to an absolute minimum, consistent with the maximum power output expected from the engine. A valve material should then be chosen which, in addition to high mechanical strength and durability at elevated temperatures, etc., should have a high resistance to attack by the exhaust products, particularly lead bromide.

Firstly, take the question of working temperature; the problem is to get rid of the heat in the exhaust valve head by suitable methods. One of the main routes for the dissipation of the heat is via the valve seat to the seating in the

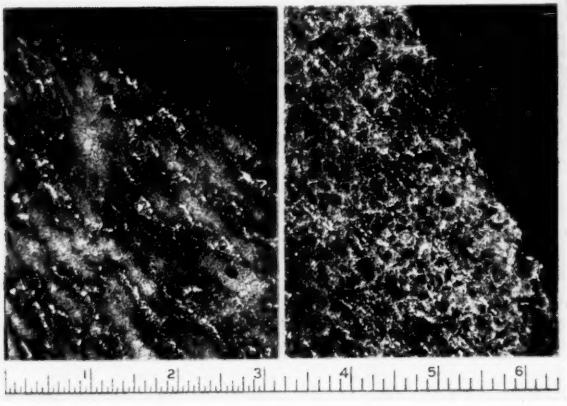
cylinder, when the valve is at rest during the normal operational cycle. The " heat dissipation capacity " of the valve seatings must therefore be good.

The experience we have in this country, and on the Continent, seems to indicate that the valve seatings in the cylinders themselves (these have usually taken the form of rings of some material such as aluminium bronze, which are inserted into recesses made at the combustion chamber end of the exhaust port or ports) exercise a considerable influence upon the condition of the seat of the valve itself and therefore the life and behaviour of the latter.

In this connection it is interesting to note that the question of the conductivity factor of the seat insert material appears to be of secondary importance, provided that the coefficient of expansion of the material is as near as possible



(A) Showing skin formation unetched.
(Magnification 150 diameters.)



(B) Section of undamaged portion of seating. Etched ferric chloride.

(C) Section through badly pitted area. Etched ferric chloride.

(Magnification 130 diameters.)

FIG. 7.

to that of the cylinder head material in which the insert is fitted and the method of fitting is satisfactory, *i.e.*, good thermal contact maintained. Its capacity for getting rid of heat is much greater than the amount of heat which the valve can give up to it.

The important features which a valve seat insert should possess are a high resistance to corrosion attack and good surface hardness or, in any case, toughness. One would prefer " hardness " to " toughness " either of the insert or the valve seat or both, if possible. Corrosion resistance appears to be the principal answer to valve burning troubles and, in addition, the provision of a hardened surface in one or both cases seems to prevent abrasion of the surfaces by any scale which becomes detached from the valve head and which may be temporarily trapped between the valve seat and insert, tending to spoil the thermal contact between them. This raises the working temperature of the former and may eventually cause " blow past " of the gases when the valve should normally be closed, finally leading to valve burning or " guttering." Due to the increased temperature, further scale will be formed on the head of the valve; the trouble then becomes accumulative and it has been known to lead to pre-ignition owing to the scale on the valve head becoming incandescent. A corrosion resistant and hard, or very tough, insert will go a long way towards preventing a valve from burning, because its surface remains unimpaired under the conditions described above and this tends to keep the valve seat surface in good trim.

The power developed per exhaust valve of the modern aviation engine is considerable and production engines are now in operation developing 80 b.h.p. per valve. In some cases this figure is exceeded. It may be of interest to record here that the figure reached for the Rolls-Royce " R " engine, produced for the Schneider Trophy Contest and the World Air Speed Record for 1931, was about 116 b.h.p. per valve.

The rate of development of the modern aviation engine is such that great difficulty is being experienced in keeping the exhaust valve temperature within reasonable limits. It has been apparent, during the last year or so, that however efficient the design of the valves and inserts, it is difficult, if not impossible, to get rid of the heat adequately in this manner. Obviously, the hotter the exhaust valve the more limited are the capabilities of the engine with fuels of given octane value.

This has led to the development of the internally cooled valve. The internally cooled valve is a valve having a hollow stem and sometimes head, partially filled with a medium which will efficiently transfer some of the heat from the valve head to the cooling medium of the engine (air or liquid) via the valve stem and guide. The filled valve stem is hermetically sealed.

Such valves were thought of many years ago at the R.A.E., Farnborough, but were discarded after a certain amount of experimentation. The author believes that the cooling mediums then tried were water and mercury.

The use of water in a sealed valve stem was most unsatisfactory and at working temperatures, high internal pressures were set up, causing swollen and often burst valves.

About six years or more ago this type of valve was revived by one S. D. Heron, an Englishman, who was then working in America, but who had been associated with the original development at the R.A.E. Heron, however, discarded the liquids referred to above and tried mixtures of salts.

In the first place, he made up a eutectic mixture of potassium and lithium nitrates and partially filled the hollow stem of the valve with the mixture, afterwards sealing up the stem.

The use of these salts, although bringing about great improvement in the valve condition, was not, however, entirely satisfactory, due to the fact that their employment sometimes subjected the valves to high internal pressures. The cause of these high pressures was that the mixture had a low thermal conduc-

tivity which meant that the engine, on starting, warmed up the valve head and melted the salt mixture locally and the rest of the salt column in the stem remained " frozen " or solid, with the result that very high pressures were generated by the already melted salts, causing swelling and cracking of the valve stems.

After some investigation the employment of the eutectic salt mixture was discontinued and its place taken by metallic sodium. Sodium has many advantages over the salt mixture as a filling and cooling medium for this type of valve. It (sodium), unlike the salt mixture, has little or no mechanical strength and therefore does not give rise to stresses in the valves when it is melting. The melting point of sodium is relatively low and its thermal conductivity is high (about 0.3 c.g.s. units)* being in the order of nine times that of the austenitic steels. This latter feature means that, upon heating, the column will melt almost at once throughout its whole length. Sodium has good " wetting " properties which are important in order to " pick up " or " collect " the heat from the surfaces of the valve.

Below are given some details of sodium and a eutectic mixture of potassium and lithium nitrates.

TABLE II.

	Sodium.	Eutectic.
Melting point °C.	97.5 (207.5°F.)	129.4 (265.0°F.)
Boiling point °C.	880 (1616.0°F.)	—*
Heat equivalent of fusion cal. per gm.	31.7	55†
Specific gravity	0.97	2.2

* Potassium Nitrate decomposes at 399°C. (750°F.)
† Approximate.

Suitable Valve and Insert Materials and Combinations

It has been mentioned beforehand, that a high degree of corrosion resistance and hardness, or toughness, of the valve seats and those of the inserts is necessary to ensure good length of valve life.

The material most generally used up to the present time for inserts is aluminium bronze, which, according to its specification and treatment, will have a Brinell number between, say, 220-260 or about 25-30 Rockwell C. hardness. Nickel-iron-aluminium bronze has also been used, in its cast form, in America, and can be heat treated to give a Brinell hardness of over 300. Monel metal is another material which has given satisfaction.

Aluminium bronze is still used, but one would hazard a guess that, even for engines of moderate or low specific power output, it will, in the near future, be superseded by special alloy steels. In addition, it is the author's experience and, he believes, the experience of others, that the use of alloys having a high copper content is not satisfactory for engine parts subjected to high temperature and duty in the presence of the products of combustion of leaded fuels.

Special alloy steels are already being tried, and in fact one or two manufacturers have done a considerable amount of running with steel inserts and intend to standardise them in all their future models.

The materials generally favoured are those of the semi-austenitic or austenitic variety and in some cases are similar to those used for the valves themselves. They are usually high in nickel and chromium and have comparatively high coefficients of expansion, close to the expansion characteristics of the cylinder head material (aluminium alloy), and this assists in keeping the inserts in place.

* 1 c.g.s. unit=gm. cal./sq. cm./cm./°C./sec.

These steels generally have a good resistance to corrosion and scaling at high temperatures and there are some particular brands which are exceedingly tough and " work harden " to a high degree. Needless to say, they are also difficult to machine, but this is not an insuperable difficulty and has been tackled successfully. Notable among these is N.M.C. (nickel, manganese, chromium), a high expansion steel produced by Firth's. Its analysis is as follows:—

TABLE III.

N.M.C.

Ni	...	...	...	12.0%
Mn	...	...	...	5.0%
Cr	...	...	...	3.5%
C	...	...	...	0.5-0.6%
Si	...	...	...	0.5%

This steel (N.M.C.) has a coefficient of expansion which lies between that of aluminium bronze and the aluminium alloys generally used for cylinder head material, being 0.0000223 between 200°C. and 300°C.

N.M.C., particularly, and the steels high in nickel and chromium, such as K.E. 965, Firth's " H.R. Crown Max," Hadfield's " Era " Class, should be satisfactory for insert materials, but if still further durability is required the seat surfaces of these materials may be treated with " stellite," giving them a high degree of hardness. Stellite, however, is not only used for its hardness value, but also for the more important reason that it is highly resistant to " hot " and " cold " corrosion attack.

The " stelliting " process will be dealt with under a separate heading and at a later stage in the paper.

As a matter of interest, the use of stellite and of high tungsten steel for inserts fitted in the cast iron cylinder blocks of automobile and bus engines has been quite a common practice for some time now, particularly in America.

Practically two and three times the length of service is obtained from exhaust valves with these seats and they remain in a better average condition throughout their working life.

It is extraordinary how a change in insert material affects the valve. Many cases have come to one's notice where valves have burned when operating against aluminium bronze inserts and have been completely cured on going over to steel inserts, either with or without " stelliting."

In the early days, when trying out leaded fuels and with the harsh valve gears then prevalent, there were many cases where the valve had hammered into an aluminium bronze insert by as much as $\frac{1}{32}$in. to $\frac{1}{16}$in. in 50 to 70 hours' running. Few or no cases of this now occur, but where a valve has become burned and an insert of aluminium bronze used, a close inspection of the seat surface of the latter will reveal that a certain amount of " picking up " has occurred, probably due to corrosion attack of the insert surface. Incidentally, it has been found that the " striking " speed, *i.e.*, the speed at which the valve closes on to its seat should not exceed 2 feet per sec., and 1.5 feet per sec. is preferable. This was difficult to achieve, particularly on some of the air-cooled engines with uncompensated valve gears which worked with large clearances when hot.

The question of the design of internally-cooled exhaust valves, and also inserts, will be discussed together with the means of fitting the latter, but before doing so it might be as well to summarise the valve and seat situation as it stands and give a few suggestions, backed by recent experience, regarding suitable valve and insert combinations.

The following combinations could, in the light of recent experience, be tried with advantage:—

(*a*) A valve of austenitic steel, such as K.E. 965, Hadfield's " Era " class or Firth's " H.R. Crown Max," working against an insert of similar material or N.M.C., preferably the latter.
(*b*) A similar type of valve as in (*a*) " stellited " on the seat and working against insert material which is not " stellited."
(*c*) Both the valve and insert " stellited," using the same materials as in (*a*).
(*d*) An " unstellited " valve against a " stellited " insert, similar materials used as in (*a*).

The author is able to state that, in the case of (*a*), K.E. 965 valves were tried with success on prolonged tests against inserts of N.M.C. both on complete air-cooled engines and single cylinders of the same type.

In cases (*b*) and (*c*) very successful results have been obtained, but one would submit that the final combination will be as in (*c*), although the others should be quite satisfactory for a year or two yet, or at least until more experience has been gained with the " stelliting " process.

Whilst giving good results, it is felt that (*d*) does not offer any particular advantages over the other methods. If only one part is to be " stellited " it is better to treat the valve, as in (*b*), because " stellite " has good resistance to scaling at elevated temperatures and also to cold corrosion, and the exhaust valve is more subject to these troubles than the insert, since the former is essentially a " hot and dry " part.

Valves are now being tried out having a thin layer of " stellite " over the surface of the head (combustion chamber side) as well as the seat. This assists in preventing the build up of deposit on the valve head and pitting of the latter, and the procedure is to be recommended. The " stelliting " of the valve stem and neck, or throat, would also be beneficial in preventing undue wear and scaling, and should prevent corrosion fatigue to a large degree.

Some Notes and General Information on the Valve and Insert Design, Construction, and Fitting

The following information deals solely with the sodium-cooled valve and steel insert because it is felt that this combination is a direct line of development to pursue immediately, to ensure the future success of the high duty engine in conjunction with high duty fuels.

Valves

In Fig. 8 sketches are shown of the sections of two sodium-cooled valves differing in design.

(*a*) Shows the latest type of sodium-cooled valve developed in America. The hollow forged head should be noted, together with the swaged-in hollow plug or thimble at the stem end. The latter is to prevent excess heat from travelling up to the stem end, upon which the valve rockers operate, particularly in the case of the partially lubricated valve gears of air-cooled engines, where there is a risk of excessive heat getting to the valve springs and softening them.

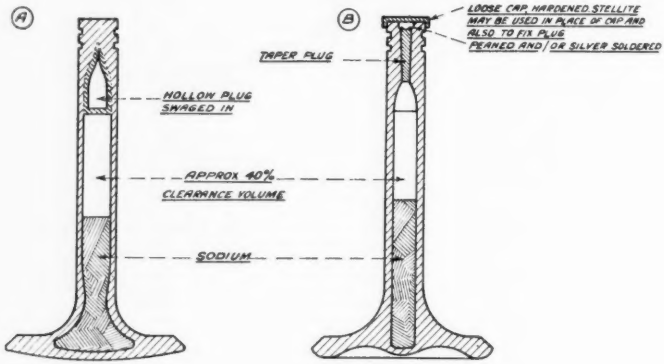
(*b*) Gives a sketch of a similar valve with a hollow stem only and it shows a different method of plugging which is also in use. The taper plug is pushed in and the material peened over it at the stem end. A loose, hardened cap is then fitted over the stem end, or a hardened tungsten steel button welded on. Quite a good idea is to " stellite " over the stem end and this will ensure that the plugging remains tight and it provides something of suitable hardness on which the rockers can operate directly.

The valve head design is interesting, and it should be noted that in one case, (*b*), the section of the material at the valve seat is in the form of a rim. If " blow past " occurs at a particular point around the rim, the valve at this point tends to become overheated, but if it is of suitable dimensions or section,

the rim allows the excess heat at the point of " blow past " to be carried around it, thus preventing local overheating. It also causes the rim to expand, tending to reseat the valve at this point.

This valve is of the modified tulip type. The full tulip head is not desirable, since, due to its greater exposed surface, it usually runs hotter than the other types and in any case the sodium is generally too far removed from effective contact with most of the head material.

The most effective valve seat angle is, in the author's opinion, one of 30°. This gives a better average valve opening characteristic than, say, one of 45°, but it is more difficult to ensure maintaining a satisfactory seating with this than with one to the latter angle, and perhaps in the case of an exhaust valve particularly, it is more important to ensure that the valve seats itself efficiently rather than to attempt to benefit by the small increase in porting efficiency offered by the former angle.


A
B
LOOSE CAP, HARDENED STELLITE MAY BE USED IN PLACE OF CAP AND ALSO TO FIX PLUG PEENED AND/OR SILVER SOLDERED
TAPER PLUG
HOLLOW PLUG SWAGED IN
APPROX 40% CLEARANCE VOLUME
SODIUM

TWO TYPICAL EXAMPLES OF SODIUM FILLED VALVES.

FIG. 8.

The amount of sodium put into a valve is approximately 60 per cent. of the total internal volume of the valve after an allowance has been made for plugging. In other words, after plugging, a clearance volume of about 40 per cent. should be provided.

The method of filling the valve with sodium is not usually disclosed by the valve manufacturers, but one can give a general procedure, which is as follows: The valve is heated to about 400°C.; this drives out any traces of moisture, with which sodium is highly reactive. In the meantime, the required amount of sodium (to occupy 60 per cent. of the final internal volume) is weighed out and kneaded into lengths of small diameter, like spaghetti. This is then introduced into the heated valve stem. A special sodium extrusion gun is sometimes used, which meters the required quantity into the valve. In the case of the large valve with the thimble type hollow plug, the sodium is usually extruded in the form of a large slug. This is placed in the valve, the thimble is driven in and the valve tip is then heated and swaged in. In all cases, after filling, the stems should be sealed while hot, so that there is as little air as possible left inside to cause oxidation.

The stage of manufacture reached before filling the valve, generally depends upon the valve material and the method of plugging adopted, and it may be necessary to carry out heat treatment after filling and plugging. This can safely be done in the case of sodium-filled valves.

Exhaust valves of large diameter are now being produced with hollow heads in order to take as much heat away as possible. The smaller valves, particularly those in liquid-cooled engines, are at the moment keeping to the hollow stem only, but as the specific power outputs rise, the hollow valve head is almost bound to be employed.

Due to the difficulty of ensuring accuracy of the section of the material in these forged hollow-head valves, another method of manufacture has been tried with some success. In this method a valve forging is accurately machined out internally, open at the head and stem ends. This serves two purposes; in the first place the valve may be completely inspected internally, and secondly, it can be designed so that the sodium is brought very close to the valve seat itself to assist in carrying away the heat immediate to the seat, instead of, as in the normal hollow head, the sodium being rather locally placed about the centre of the valve head with a fair thickness of material between it and the seat.

After the valve has been machined internally, a disc of the same material as the valve is pressed into place, to form the valve head, and fixed by "stelliting" and/or swaging. The valve is then filled with sodium from the stem end, after which the latter is plugged in the normal manner.

This method of manufacture makes for a lighter valve than the completely forged job, and low weight is important in these days of high engine speeds.

It does not seem to affect the efficiency of a sodium-cooled valve if it works in the normal attitude in an engine, or inverted, as in the lower cylinders of a radial or an inverted " in line " engine. The sodium very quickly liquefies and gets well " joggled " by the movement of the valve.

The question regarding the most satisfactory width of valve seat to employ is a vexed one. For some time the American engine firms have favoured a relatively wide seat, and in some cases the seat widths have been, in one's opinion, excessive. The tendency in the States now appears to be towards a narrower seat, particularly for engines of high specific power output using fuels containing lead.

The seat widths of some typical American valves range from 7/32in. to $\frac{1}{4}$in. for a large valve having a seat diameter of about 3ins., and from $\frac{1}{8}$in. to $\frac{3}{16}$in. for valves of 1.75ins. to 2.00ins. seat diameter. The British engines generally keep to the lower limits of the widths mentioned, and in some cases are only half the width, in proportion.

The primary reasons for using a large seat width are: Firstly, that it should allow for a greater rapidity of heat dissipation to the insert, while the valve is at rest, thus tending to keep the latter cooler, and, secondly, prevent " hammering " and " pick up " between the valve and insert. Particularly if the valve is of austenitic steel and is also running fairly hot, and if inserts of aluminium bronze are fitted.

The foregoing reasons and theories are quite sound, but it is also important to obtain good thermal contact between the seat surfaces, and to do so often necessitates a fairly high unit loading of the seats. To achieve this there are two alternatives; one is to decrease the seat width somewhat, and the other to increase the valve spring strength. The latter is obviously a retrograde step, and unless an increase in the operational speed of the engine is desired, which may necessitate increased spring strength, this alternative cannot be contemplated. One hesitates, therefore, to speak of " wide " or " narrow " seats as such, and considers that the question of width is really a compromise which is controlled by the considerations of individual engine design. Satisfactory unit loading, to

achieve good thermal contact, should, in the author's opinion, be considered of primary importance.

The author, unfortunately, has no figures to put forward for the unit loading of valve seats, but submits that little would be gained by so doing, since the best compromise would eventually have to be found by the individual engine builders to suit their particular engines, and this, again, would be affected by the materials used. There is a risk, if the seat is very narrow, that any " blow past " which may occur will cause " guttering " right across the seat, whereas with a wider seat, under similar conditions, it usually takes longer for this to occur, and it may only show up in the form of pitting.

It will be appreciated, therefore, that it is unwise to dogmatise on matters such as the foregoing.

Many valve troubles are occasioned by distortion of the cylinder head. This is particularly liable in the case of the monobloc arrangement used for the large modern liquid-cooled engines, and it has also been the cause of a large amount of trouble in some ordinary motor car engines.

The stresses due to heating and consequent expansion of the aluminium cylinder head, jacket and crankcase castings of large liquid-cooled aviation engines must be considerable. The accompanying distortion, so far as it may affect the valves, generally causes misalignment between the valve guides and inserts, or actual " ovalising " of the latter, both of which prevent the valves from seating properly and cause valve burning. Distortion is very difficult to detect or control, but if valve burning is experienced, this possibility should be the first to be investigated. The effect of distortion may be treated, for a cure, in a number of ways, such as stiffening up the inserts and designing a valve having a head which will tend to adapt itself to any distortion or "ovalising" of the insert. A valve of similar design to that shown in Fig. 8 (*b*), is suitable, with, if necessary, a much more pronounced rim. In other words, the rim of the valve, and the insert, should be regarded as two concentric rings, and the rest of the valve head connected to the rim designed to achieve this effect.

Distortion effect could also be met by employing a " stellited " surface against a softer or " unstellited " surface. Two surfaces, both "unstellited," such as a valve of K.E. 965 and an insert of N.M.C., also provide a very satisfactory combination.

The valve steels mentioned in the foregoing pages are of the austenitic variety and are well-known steels from recognised makers. These are to be recommended for use in modern aviation engines. Silchrome steel of the so-called No. 1 grade, to either of the general specifications given below, is a very excellent material as regards resistance to corrosion and scaling. Its mechanical strength when hot is not so good as that of the austenitics, but when sodium-cooled, a high degree of strength can be retained without making an unduly heavy valve; however, one would recommend it for automobile engines of normal performance rather than for aviation engines. The thermal conductivity of a silchrome steel is superior to that of the high nickel/chromium variety.

TABLE IV.

SPECIFICATIONS OF " SILCHROME No. 1."

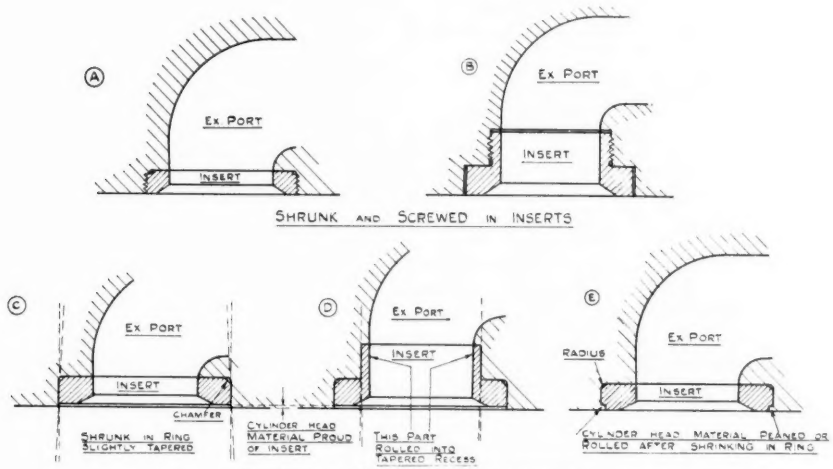
British.			American.		
C.	...	0.40%-0.50%	C.	...	0.40%-0.50%
Si.	...	3.50%-4.25%	Si.	...	3.00%-3.50%
Cr.	...	7.50%-8.50%	Cr.	...	8.00%-9.00%
Mn.	...	0.40%-0.60%	Mn.	...	0.20%-0.60%
Ni.	...	0.50%			

NOTE.—The maximum amounts of sulphur and phosphorus in the above specification must not exceed 0.030 per cent.

NOTE.—The maximum amounts of sulphur and phosphorus in the above specification must not exceed 0.025 per cent.

Finally, the design of the valve guide for a sodium-cooled valve is very important, because the stem has to deal with extra heat to normal and unless it can get rid of it to the cooling medium in an efficient manner a high degree of guide wear will result, causing progressive overheating of the valve stem as the wear increases. Therefore, attention should be paid, in the design stages, to the adequate provision of finning, etc., at or about the exhaust port and guide, in the case of the air-cooled engine, and ensure that the guide has more or less direct contact with the coolant, in the case of the liquid-cooled engine. Also, experimental running should be done in order to arrive at correct clearances between the valve stems and the guides.

The valve guide materials can be similar to those normally used, such as aluminium bronze. Adequate provision for lubrication must be provided.



Various methods of fitting inserts.

FIG. 9.

Inserts

Fig. 9 gives rough sketches of different types of inserts and the methods of fitting them.

The screwed insert is in general use in this country, whereas in America the plain type is practically universal.

Purely as a matter of personal preference one favours the American method of shrink fitting a plain ring, and considers that it has adequate surface area, on its side and base, to obtain good thermal contact with the cylinder head material.

The prevailing British method of screwing in the inserts does not, on first considerations, seem to be so satisfactory, but it is rather difficult to dogmatise on such a point of individual design. In the first place it is very difficult to ensure accurate cutting of the thread of good profile in aluminium, and secondly, having screwed the seat home, it tends to bear hard on one side of the thread only and loses the benefit of good thermal contact over what would at first appear a large surface offered by the threads.

In the case of liquid-cooled engines it does not seem to matter so much whether the inserts are shrunk screwed or shrunk in only. In fact, it is probably difficult to shrink satisfactorily at any appreciable temperature, in the case of a monobloc casting, because of its relatively complicated design. For the cylinder

heads of large air-cooled engines, however, there is now generally little trouble in this respect, particularly in the case of forgings, and it is quite usual to take them up to 300°C. or 400°C. before fitting the inserts.

An important point in this connection is to ensure that the section of the material surrounding the insert recess is such that the stressing is reasonably uniform when the cylinder head is heated or cooled, either during the process of fitting the inserts or under working conditions. This is, naturally, a question of design which, in addition, should provide a firm bed in which the insert is to rest.

*" *Cold* " *Corrosion*

The question of " cold " corrosion, that is to say, corrosion of certain parts of the engine when the latter is lying idle, is not now regarded as a really serious problem. This does not mean that such attack is not serious in itself, but rather, by the employment of suitable technique, it can be avoided.

The cause of " cold " corrosion is generally accepted to be as follows: When an engine comes to rest a certain amount of condensation takes place, particularly in the case of a cylinder in which the exhaust valve has stopped in the open position. Any lead bromide present will also condense and this with the moisture present, gives rise to corrosive action particularly on steel parts. Lead bromide, due to its relatively high boiling point, about 920°C., will condense immediately the engine stops and before considerable cooling takes place.

Mardles,[8] however, puts forward another contention, which has been borne out by his own experimental work. He states that: " The reaction product appears to be relatively inert lead oxy-bromide (Pb Br_2 Pb O). The main trouble appears to be due to the action of condensed water on the small residual amount of lead oxy-bromide, to form wet corrosive substances when the engine is idle."

If lead bromide itself is heated strongly in air or oxygen it tends to form an oxy-bromide, but it melts, undecomposed, in a neutral or bromine atmosphere.

The principal points attacked by " cold " corrosion are the exhaust valve stems and the cylinder barrels. The extent to which they are attacked is influenced by the materials used and also their working conditions.

The general treatment, to avoid attack, is to ensure that the parts concerned are well covered by a film of mineral lubricant.

If it is known that an engine is to be stored for any length of time (say a month or more) it is a good plan, after stopping it, to inject half to a pint of hot oil into each cylinder. Some consider that cold oil is better because it provides a thicker film.

The engine should be turned at fairly frequent intervals, of about a week, which after all is, or should be, the normal procedure for ordinary storage, whatever the fuel used.

In the case of air-cooled engines, where the valve gear is often of the " open " type and grease lubrication is used (no actual oil circulation around the gear is employed), provision should be made for an oil gun or similar attachment to the valve guides, so that they can be given a " shot " on occasion. This is particularly useful when the engine is out of use for a short period of, say, a week or so.

The engine should also be turned during this period, as in the case of its storage over longer periods. Some provision could, perhaps, be made to introduce measured quantities of mineral oil to the cylinders, via the induction pipe, at low throttle openings and before stopping the engine.

* Since writing this paper a report has just come to hand which deals further with the treatment of cold corrosion. The work has been done by the U.S. Army Air Corps and this body has kindly consented to its general release. Therefore, the report is published in full, under Appendix V, at the end of the paper.

[8] Letter to " Engineering," October 20th, 1933.

Storage tests have been done in this country on engines which have run for some time on leaded fuels of high concentration (4 c.c.'s per gallon). The periods varied from one to two months and the storage was done under Air Ministry conditions for the normal storage of aviation engines and also under A.M. supervision. In all cases (both water and air-cooled engines were subjected to the test) cold mineral oil was used, but upon stripping and examination no detrimental corrosion attack was observed. There was, in the case of a few cylinders, a very light line of what appeared to be rust at the upper end of the bores. This, however, is a vulnerable point in all engines, whatever the fuel used, and in the cases cited here no deleterious effect to the surface of the steel was observed.

The use of " nitralloy " or " nitrided " materials in this connection has been queried, but our experience here and in Europe seems to indicate that so long as the parts made from these materials are kept well lubricated, little or no trouble is encountered. Adequate lubrication is naturally quite possible with, say, cylinder barrels, but the use of completely nitrided exhaust valves is not recommended, although the valve stems may be treated in this manner and are quite satisfactory so long as the nitriding is not carried too far down to the hot part of the stem.

Exhaust Pipes and Collector Rings

Since the temperature to which any parts of an engine are subjected, particularly the exhaust valves and exhaust arrangement generally, has a very definite relationship to the rate of attack by the products of the combustion of leaded fuel, it is necessary to ensure that they are kept as cool as possible under working conditions.

The exhaust valve question has already been dealt with and the main point to consider in the case of the exhaust manifolding is to see that, by its design, it keeps as cool as possible under all conditions of flight.

A great deal can be achieved by fitting the manifolding in a suitable position relative to the engine (consistent with aerodynamical efficiency) and also ensure that its internal volume or capacity is not restricted in relation to the cylinder capacity.

The usual material employed in the construction of exhaust manifolds is mild steel which, after forming, is welded and riveted.

Mild steel, although fairly satisfactory, is not the best all-round material to use, and is very prone to split, due to a combination of temperature variation and vibration, which cause fatigue of the material.

Steels of the stainless and/or austenitic variety are gradually coming into use, particularly in America. These are corrosion resistant to a high degree and do not scale easily.

The main difficulty with these steels is that they are difficult to weld satisfactorily, due to the fact that it is very easy to overheat them during the welding operation and this upsets their structure and they no longer retain their properties.

However, their satisfactory welding is largely a matter of practice on the part of the welder, and if he is kept continuously working with them it is only a question of time before he becomes exceedingly proficient in judging the type of flame to use and the most suitable application period, also the appearance of the weld, etc., etc.

Exhaust collector rings of stainless steel are, one understands, very generally used by the military machines in the U.S.A. The use of mild steel rings has been general with the civil aircraft operating concerns in the States, and although no great trouble was experienced from their continued use in conjunction with that of leaded fuels, it is understood that they are being replaced with stainless steel rings as occasion permits.

Sparking Plugs

There is no real difficulty in obtaining a suitable plug for operation with leaded fuel, in fact, no more difficulty than choosing one for any engine whatever the fuel used. In either case a satisfactory choice largely resolves itself into a matter of practical test.

Any plug trouble which may occur with a leaded fuel is generally one concerning deposit built up on the insulator, causing electrical breakdown or shorting and often overheating. Scaling and reduction of the electrode tip also occur.

The design and heat capacity of the insulator and the internal volume of the plug, naturally, have great influence upon the rate at which deposit builds up.

While a certain amount of experimentation has been carried out with plugs, in relation to leaded fuel, it is not really possible to lay down any hard and fast rules regarding a suitable plug for a particular engine, but the following rather general notes may be of assistance.

The deposit found on a plug insulator is composed mainly of lead bromide with some lead sulphate. The latter is usually present to a greater or lesser degree in any deposits from leaded fuels, depending upon the sulphur content of the fuel concerned. However small this content, there is always sufficient to combine with lead present and form measurable amounts of lead sulphate.

The deposit is hygroscopic, but provided that it has not actually picked up any moisture it is an inferior electrical conductor when cold, although it improves in this respect when hot.

Cases have occurred where plugs have run so cool that this, together with a fuel having a high lead concentration and an engine which was " idled " for long periods for warming up purposes, caused deposit to build up very rapidly and " misfiring " occurred when putting the engine on load.

Such cases illustrate the fact that one can obtain rapid deposit build up if the plug runs too cool. The cures in the above cases were effected by the choice of hotter running plugs or increasing the speed of idling somewhat, or both. In the case of mica insulators, particularly, it assists in the reduction in the rate of deposit build up if the mica is given a high degree of polish.

If the rate at which the deposit builds up is high, one will often notice a tendency to misfire under part throttle conditions or there will be a definite failure to start. This is generally due to the deposit picking up moisture, which causes shorting. Sometimes, once the engine has started, this misfiring disappears, when running under load conditions, due to the heat drying up the moisture present.

Gradual deposit formation may not make itself felt until the engine, after fairly long periods of operation suddenly starts misfiring or drops in speed. This is due to the deposit becoming well baked on to the insulator and causing a breakdown in electrical resistance, due to a rise in temperature of the former. A plug which runs slightly cooler is often the cure for this trouble.

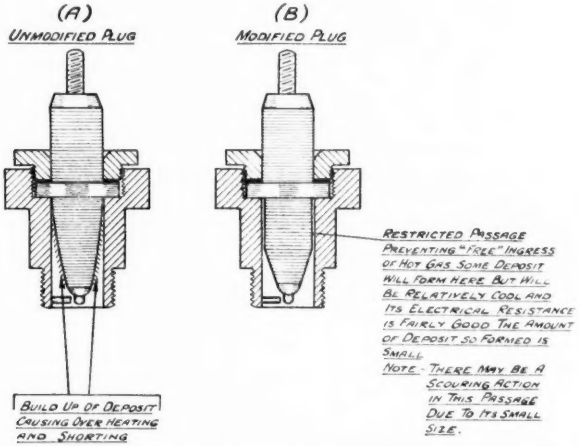
Some trouble has been experienced with plugs which employ " ceramic " insulators. This is a heat-resisting substance and is a more or less synthetically prepared product of good electrical resistance. This type of insulator was generally treated with glaze for it to be effective, electrically. Under certain conditions the deposit attached itself to the glaze and if the latter contained any lead, more or less complete amalgamation between the glaze and the deposit occurred.

Further deposit then baked on and the plug eventually began to misfire. Now if the deposit was removed by scraping, the glaze also came away with it, leaving the " ceramic " insulator bare, which rendered it unsuitable for further work.

This particular type of plug is more generally used for automobiles, but in any case these troubles do not now persist. The design and manufacture of the

" ceramic " insulator has in some cases been modified to dispense entirely with the glazing treatment at its " operating " end, and the insulator is designed so as to deal more efficiently with the temperature conditions under which it has to work.

The sketches in Fig. 10 show a certain type of mica plug where, in (*a*), it was unsuitable for use with leaded fuels, due to shorting and deposit build up at the upper end of the insulator, and in (*b*) the modification which made it suitable and improved its useful life by six or seven times. In this case, advantage was taken of the fact that the lead deposit, when cool, is not a good electrical conductor and the restriction at the upper end of the insulator permitted any deposit, formed there, to remain relatively cool and preserve its electrical resistance. Any deposit on the insulator, near the electrode tip, naturally remained hot, but the relatively large clearance between it and the plug body prevented shorting.


(A)
UNMODIFIED PLUG
(B)
MODIFIED PLUG
RESTRICTED PASSAGE PREVENTING "FREE" INGRESS OF HOT GAS. SOME DEPOSIT WILL FORM HERE BUT WILL BE RELATIVELY COOL AND ITS ELECTRICAL RESISTANCE IS FAIRLY GOOD. THE AMOUNT OF DEPOSIT SO FORMED IS SMALL
NOTE - THERE MAY BE A SCOURING ACTION IN THIS PASSAGE DUE TO ITS SMALL SIZE.
BUILD UP OF DEPOSIT CAUSING OVER HEATING AND SHORTING

Sketch showing modifications made to mica type plug to suit air-cooled engine running on a " leaded " fuel.

FIG. 10.

The question of the erosion or corrosion of the plug electrodes has been brought up from time to time. This is also largely a matter of material and temperature and is often overcome by the use of a cooler running plug. If it is not satisfactory to use such a plug it might be worth while to try stelliting the exposed part of the electrode. This has already been done with a certain amount of success. It is difficult to avoid overheating such a small mass of material during the stelliting process, but it is possible to fit a complete tip of pure stellite. Tungsten and also pure nickel are satisfactory materials for electrode tips. Aluminium steel has also been suggested, but the results are not yet to hand.

One would reiterate that the plug question, where leaded fuels are concerned, is not a difficult or critical one, but the troubles given here together with the explanations regarding them should enable engine operators and plug manufacturers to make a satisfactory choice in the first place, or eliminate quickly, any troubles which they may be experiencing.

Some Notes on " Stelliting "

This paper would not be complete without some reference to the " stelliting " process, and although it has been in use for some time, its application to the

valves and seat inserts of aviation engines is only a relatively recent development, consequently the following information may be of some assistance.

" Stellite " is a material composed largely of cobalt and chromium, between 50-65% of the former and 30% of the latter together with tungsten, which may vary in proportion from about 4% to 20%. The amounts of the constituents vary according to the particular grade and degree of hardness required.

Both at low and elevated temperatures its resistance to wear and oxidation is excellent. It is particularly effective in resisting, at high temperatures, corrosion attack by lead bromide or the products of its decomposition. The treatment of valves and inserts consists, briefly, of applying a layer of stellite to the seat surfaces, this being done by means of an oxy-acetylene torch.

" Stelliting " is not actually a welding process, since fusion of the stellite and the material of the part being treated is not desired. It might be described as a high temperature brazing process.

Considerable practice is necessary and a special technique adopted, in order to obtain successful application of " stellite." The particular grade of " stellite " used is also of great importance.

The Haynes Stellite Company, of Kokomo, Indiana, U.S.A., appear to be the principal firm in that country who have large experience both in the manufacture of suitable grades of " stellite " welding rods for particular purposes and also regarding their application.

The particular grade advised for exhaust valve seats and seat inserts is No. 6. This contains, approximately, 65% cobalt and 27% chromium, 4.0% tungsten, 1.25% carbon and 2.7% silicon. It has a hardness value of about 45 Rockwell C. and a melting point of 1,276°C.

Whilst this grade, No. 6, does not have the hardness of some of the others, it is more ductile and less liable to crack when used upon steel having high expansion characteristics. It has, however, been found to be sufficiently durable for the purpose even in the case of extremely hot valves having high seat loading.

Handforth[9], in that very valuable paper of his, mentions the work which he has done with regard to the application of stellite to exhaust valves, and one would recommend that this be studied very carefully, since it contains much information. Handforth used a grade, known in this country as " deloro," which is considerably harder than the No. 6 mentioned above. Its composition is, roughly, as follows: Cobalt, 40-50 per cent.; chromium, 25-30 per cent.; between 15 and 20 per cent. tungsten, and 2.5 to 2.75 carbon, with a Rockwell C. hardness of 58. This corresponds to No. 98 grade in the States, and is not advised for the purposes stated here. Handforth mentions that he experienced trouble, due to cracking, with this particular grade, but attributed this to the class of steel used, *i.e.*, cobalt-chrome, rather than to the brittleness of the stellite itself. He, Handforth, appears to have overcome this trouble subsequently by the use of austenitic steels, but one would prefer the No. 6 grade—particularly for these high-expansion steels.

The application of stellite to valve steels, as mentioned previously, requires great care and practice, particularly with regard to those steels in the austenitic class. The valve material must not become overheated during the application of the stellite. With martensitic steels, should overheating occur, it is possible to restore their structure by heat treating after applying the stellite, but this is not possible with the austenitic steels, since excessive grain growth occurs with the latter which cannot be eliminated by further heat treatment.

The type of oxy-acetylene flame and the amount of heat applied to the part to be stellited are all important. A reducing flame with a considerable excess of acetylene should be used.

[9] " Metallurgical Problems arising from Internal Combustion Engine Valves," by J. R. Handforth. Read before the Iron and Steel Institute.

The torch used should be of the low-pressure type, and the oxygen supply should be varied as far as possible with the pressure regulator on the oxygen bottle rather than with the valve on the torch itself.

The tip used on the torch should be the smallest which it is possible to use for the part to be welded, and the oxygen supply regulated so that the cone, when applied to the molten stellite, does not tend to blow it or penetrate it. A suitable cone merely causes a pool of molten stellite to spread in area.

It is most important that the steel backing be heated to the *minimum* temperature that will allow the stellite to flow over the surface of the steel and wet it.

The importance of having a strongly reducing flame is, apparently, that this flame, which deposits carbon on the surface of the steel, results in raising the carbon content of the surface film to such an extent that its melting point is very considerably lowered, and thus a surface film on the face of the steel

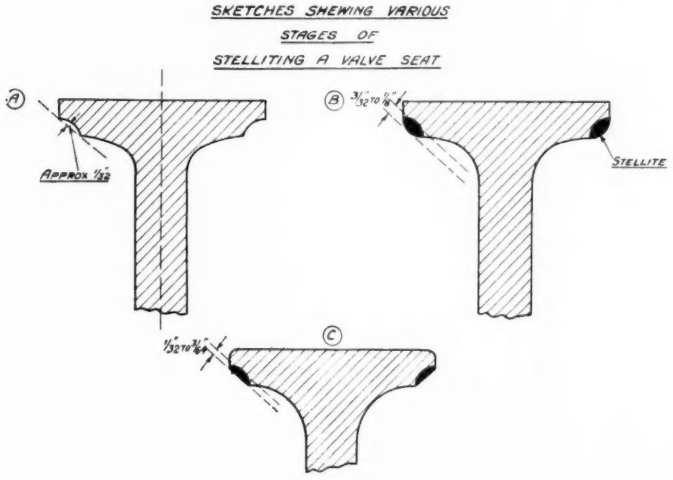


FIG. 11.

can be practically molten, while 0.005in. below the surface the steel is not even overheated. The presence of carbon also improves the flow of the stellite.

Some information concerning the type of flame, etc., is furnished in the copy of a sheet issued by the Haynes Company and reproduced at the end of the paper.

The work to be stellited, such as a valve, is usually placed upon a heavy block of pure cast copper, and the whole is arranged so that it can be rotated at will. Provision should also be made so that the surface to be stellited, such as the valve seat, can be placed in a horizontal position during the operation. The copper block is heated by the torch before the valve is placed in position upon it.

The whole is then rotated and the valve heated between 760°C. and 870°C. before applying the stellite. After heating to within the temperature range mentioned, rotation is stopped and the torch applied to a point on the valve seat until a temperature of about 1,090°C. is reached locally. The cast welding rod of stellite, approximately $\frac{1}{8}$in. in diameter, is then fed into the flame and a small bead representing about $\frac{1}{8}$in. length of the rod is deposited on the steel. This readily " wets " the steel if the latter has been sufficiently heated and not unduly oxidised. As soon as " wetting " has occurred, further welding rod is fed into the flame to increase the area of the molten pool.

By a suitable combination of torch positions relative to the valve seat and the pool of molten stellite, and as soon as the pool has " wetted " the steel, the addition of further molten metal results in the stellite, in its molten state, spreading around the seat ahead of the torch. As a result of this spread of the molten stellite, the flame cone should not be applied directly to the steel once the pool is started, thus oxidation and overheating of the material is almost entirely eliminated.

When the stellite has been deposited over the entire circumference of the seat, the torch is carefully worked over the junction of the starting and end points of the deposited metal. In some cases two layers of stellite are deposited, which means going twice around the seat circumference. This involves partial remelting of the first ring of stellite and generally smoothing up the surface.

The thickness of the deposited stellite is generally $\frac{1}{8}$in. at the middle of the seat, when a finished thickness of 1/32in. to 3/64in. is desired. See Fig. 11.

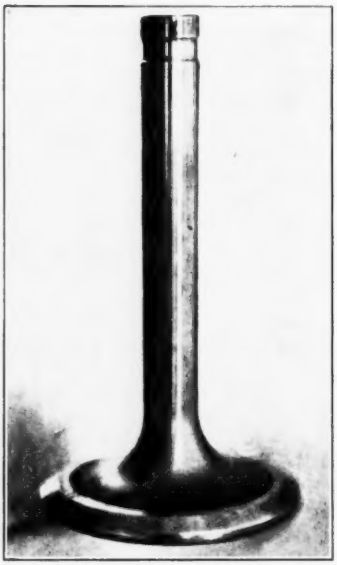


FIG. 12.

FIG. 13.

The method of stelliting valve seat inserts is identical with that used for valves, with the exception that two copper blocks are employed, *i.e.*, one outside the insert and one placed in the orifice formed by the insert ring.

Fig. 12 shows a typical example of an exhaust valve of a large American radial engine.

The valve has a hollow forged head, sodium filled, and both the seating and valve head are stellited. This valve measures about 3ins. across the outer diameter of the seating, and weighs approximately one pound in its completed form.

Fig. 13 gives a sectional view of the same valve. Note the hollow swaged-in plug at the stem end, and also the thickening up of the stem section at the neck. This valve is a remarkable example of accurate forging.

The illustration in Fig. 14 shows stellite deposited on a rough machined valve of martensitic steel. The segment cut from the valve head shows up the section.

Fig. 15 shows a valve of the same type as Fig. 14, but it is of austenitic steel similar to K.E. 965 and is the product of another manufacturer. Note the difference in the stelliting process.

FIG. 14.

FIG. 15.

FIG. 16. (*Magnification* × 100.)

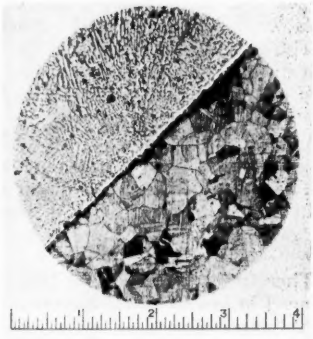


FIG. 17.

Figs. 16 and 17 show the bond and grain structure of the backing of stellite No. 6 deposited on steel of the following composition: Cr. 18 per cent., Ni. 8 per cent., C. 0.10 per cent. The deposition in Fig. 17 was the initial effort of a concern entirely without experience in the application of stellite to austenitic nickel/chromium steels.

The foregoing represents a preliminary investigation from the standpoint of an observer not trained in welding, but it is based upon the current practice of firms having large experience of the application of stellite.

An idea of the work involved in the actual deposit of stellite may be gained from the production rates on valves and inserts of 1½ins. to 1¾ins. diameter. The rate on expensive hollow head aircraft valves of this size is about six per hour, and of inserts for 'bus engines 12-20 per hour. Very rapid operators reaching the latter figure.

The overall scrap of 1¾ins. 'bus engine inserts does not exceed 5 per cent., and is usually less.

The scrap on aircraft valves is rather difficult to estimate, but at present facing a valve seat with stellite appears to increase the cost of the finished valve by about 10 per cent., which includes allowance for scrap of the relatively expensive valve body.

General Notes on Engine Operation with Leaded Fuels

The internal appearance of an engine which has run on a fuel containing lead, differs somewhat from that usually associated with the more ordinary fuels.

The deposit from the use of the former fuel is harder in nature and perhaps more adherent than that of the latter. Its colouration is also different, being white to greyish white on the cooler parts of the combustion chamber and reddish brown on the hotter parts.

This is due to the presence of lead bromide. There is, sometimes, a yellowish tinge to the deposit which may be accounted for by some lead sulphate present in the deposit.

Where a part, such as an exhaust valve, has been running unduly hot, the deposit is generally exceedingly adherent to the valve head and has a dark " steel " grey appearance.

After the usual running time between overhaul periods, and under normal conditions of operation, the deposit can be removed quite easily with a scraper or stiff wire brush of the file card type.

Scale which has become very adherent to the exhaust valve head, as described in a previous paragraph, may be removed by sand blasting. The stem should be protected, beforehand, by rubber tube or a piece of friction tape.

The dye which is present in all leaded fuels is particularly useful for the relatively complicated fuel systems used in aviation engine installations, since it shows up, almost immediately, any leaks which may be present. It is added in almost minute concentrations, approximately 1.67 grammes per 100 gallons of fuel, consequently there is no risk of deposit forming in the fuel system. In addition to which the dye is completely soluble in the fuel.

There is, however, one important point to observe—a leaded fuel should not be exposed to the light for any length of time, since this has some photo-chemical effect on the lead, causing salts to be " thrown down," and also the dye fades out.

Therefore all samples of leaded fuels collected, say, for examination, should be placed in sealed metal containers.

Although mentioned previously in the paper, one would like to repeat, that under all normal storage conditions no trouble need be anticipated with leaded fuels.

Some queries have arisen regarding the effect of leaded fuels on the materials used for aircraft fuel tanks.

No trouble has been experienced in the case of tanks manufactured from the usual aluminium alloys, but with regard to those particular alloys which contain a large percentage of magnesium, such as elektron, there seems to be some doubt as to the advisability of employing them for fuel tanks at all.

The author's experience to date is that corrosion trouble is experienced with magnesium alloys when water is present in the fuel, whether the latter contains lead or not. If it contains lead, then the corrosion attack appears to be somewhat accelerated. From this one deduces that the presence of water is really

the deciding factor, but it is almost impossible to avoid a certain amount collecting in fuel tanks. The author suggests, however, that magnesium alloy tanks could be designed with provision for a large sump of some material which does not suffer from this corrosion attack, such as pure aluminium, etc. The sump would be large enough to deal with the maximum quantity of water likely to accumulate, and deep enough to prevent any water reaching the joint between the sump and tank, in order to avoid the possibility of electrolytic action. The sump could be fitted to the tank with stainless steel bolts and " langite," or similar material used, to make the joint. One believes that investigations are proceeding, and some degree of success obtained by treating the magnesium alloy in a particular manner.

There has been no trouble reported regarding the use of magnesium alloy castings for carburettor bodies, supercharger casings and induction systems, etc., when employing ordinary or leaded fuels. This is understandable, since there is little risk of water being present and resting on the surface of these parts for any length of time, as is the case with fuel tanks.

Engine Tests and the Influence of Increasing Concentrations of Lead

When considering the duration of engine tests in order to ascertain the effect of leaded fuel upon the engine parts, it is the author's opinion that no tests of less than 100 hours' duration are of value.

The experience in this country and on the Continent, over a number of tests, indicates that most failures, due primarily to exhaust valve trouble, occur after about 50 to 70 hours' running. One advances no particular reason to account for this. These are not always failures due to gradual valve burning over a number of hours. In many cases an engine has run for about 70 hours quite satisfactorily, but after starting up for the next 10-hour period it has burned out a valve in a few hours. This points to the fact that scale, which built up during the previous running, becomes somewhat loosened when the valve cools down after a run, and pieces then become detached after the engine has been started up again, and get trapped and pounded between the valve seat and insert.

In order to promote rapid engine development and to make full use of leaded fuels, the knock rating of the finished fuel should be decided upon in the first place, after which a basic petrol chosen, having an initial anti-knock value which demands a fairly large amount of lead in order to attain the required final value. Say between 3 c.c.'s and 4 c.c.'s per gallon in the case of engines for civil purposes, and from about 4 c.c.'s to 7 c.c.'s per gallon for military development.

This will ensure that the engine is capable of giving satisfactory operation with any concentration met with in service over all parts of the world, even although it may eventually be provided with a fuel, the basis of which only requires a very small amount of lead—say, about 1 c.c. per gallon—in order to reach the desired anti-knock value.

With reference to the influence of increasing lead concentrations upon the life and general reliability of the engine; there are many contentions regarding this aspect of the leaded fuel situation, and in general the consensus of opinion appears to be that an increase in lead concentration gives the parts concerned a harder time by increasing the rate of deposition of the lead products of combustion.

One is not substantially at variance with this view, and has always stipulated that tests should be carried out on the lines suggested in the previous paragraphs of this section. It is quite feasible to suppose that an increase in the amount of lead must generally show up in the form of a greater rate of deposit built up.

However, the following points are put forward as a matter of interest.

Firstly, the American view, backed by six or eight years of intensive experiment and use of leaded fuels, is that increasing concentrations of lead tend

to increase the rate of deposit built up which may lead to trouble previously dormant.

Secondly, tests have been carried out by the Air Ministry, at the works of the aviation engine firms in this country over the last two years. These tests were made on the representative types of engines in service, and the results did not completely bear out the American experience. The tests took the form of standard Air Ministry type tests of 100 hours' duration, for Service engines, and made use of a " straight run " fuel containing 4 c.c.'s of " lead " per imperial gallon. This fuel was slightly superior in knock rating to that laid down in the late D.T.D. 134 fuel specification; having an octane value of about 79/80 under D.T.D. 134 conditions of test.

The interesting point about these Air Ministry tests is that valve failure, due to burning, was experienced in some cases and occurred in about 50 to 70 hours of running. Further tests of 100 hours' duration were then made after completely reconditioning the engines concerned, but a fuel having only 1 c.c. of lead per gallon was tried. The same class of petrol was used as the basis of the fuel and a similar knock rating to the " 4 c.c." fuel was obtained by the use of added aromatics. However, in a directly comparative test with this and the " 4 c.c." fuel, precisely the same degree of valve failure in practically similar periods was experienced with both fuels and careful estimations by weight, of the amounts of scale found on the exhaust valves in each case, revealed little increase in the case of the " 4 c.c." relative to the " 1 c.c." concentration. In other words, and from the author's experience in this country and Europe, increasing lead concentrations do not necessarily give rise to trouble or to the same ratio increase of deposits in the engine.

In these particular tests, a valve and seat insert combination of K.E. 965 and aluminium bronze, respectively, was employed. Steel inserts have since been tried and a number of tests, each of 100 hours' duration, completed with conspicuous success. The valves and inserts after these tests were in better condition than those in the prototype engines which passed the original A.M. type test on D.T.D. 134 fuel.

Further experimental but extended running of a preliminary nature has been done on single and multi-cylinder engines, fitted with steel seat inserts, using a fuel having a concentration of 7 c.c.'s of lead per gallon. The results of these runs were successful and bear out the findings of the previous tests with regard to the influence of increasing amounts of lead and no detrimental effects were observed.

With regard to the apparent variation between the results obtained here and in Europe, to those indicated by American experience, a satisfactory explanation might be that the modern American engine has been developed over the same period as that of leaded aviation fuels, consequently, a certain amount of technique has been evolved to deal particularly with their use and such points as exhaust valve and cylinder head design and cooling have undoubtedly received particular attention. A great deal more flying, with engines using leaded fuels, has been done in America, while little or none has been done in this country and practically all our leaded fuel development has been restricted to relatively severe experimental running and type tests which, one submits, are more critical than flight conditions. Consequently, most American engines have been in the position to use leaded fuels, more or less satisfactorily, for some time, but since the power ratings of the engines have increased year by year, necessitating the use of fuels of higher anti-knock values, containing larger amounts of lead, this has brought about troubles which were previously dormant. One is of the opinion, however, that any troubles experienced in America with leaded fuels of high concentration are not so much due to this feature, but rather to the increased " power per litre " of cylinder capacity at which American engines are now running under normal cruising conditions in flight.

The author will go so far as to say that if some of the older types of British engines, which failed with leaded fuel under type test conditions, had been put into the air and operated with the same fuel, they would, most probably, have given a relatively good account of themselves.

It must be remembered that some of the British engines, still in military service, were designed long before leaded fuels became generally used and their power ratings have been increased more by detail improvements over a number of years than by any radical changes in design. Consequently, such parts as valves, etc., in some cases, work at elevated temperatures and are prone to attack by the products of the combustion of leaded fuel. The concentration of lead, in these cases, has little influence, since troubles have occurred with the lowest amounts.

An interesting development has been tried with some success as a result of the experiments carried out in this country on leaded fuels, although it has been used for some time on some lorry and bus engines. This development is the employment of an interference angle between the valve seat and that of its insert or seating in the cylinder. That is to say, if the seat of the insert has an angle of 45°, the valve seat is then cut to one differing by, say, 30 minutes, so that the valve seats, mainly, on its larger diameter when cold.

One advances the following theory to account for its effectiveness in practice; when some exhaust valves are running under normal or, for that matter, high duty conditions, their heads are inclined to deform somewhat, in addition to expanding, and they then bear on the smaller diameter of the seat, at the exhaust port side. This leaves a space at the larger diameter or combustion chamber side, allowing entry of the hot gases, tending to cause overheating of the valve edge and, perhaps, corrosion of the seat surfaces.

By experimenting with various angular differences between the valve and insert, a suitable compromise may be found which allows the valve seat surface, when hot, to become parallel with that of the insert, thus maintaining good contact over the whole surface of the seat and sealing it to the ingress of hot gases.

That is to say, the valve when cold will bear mainly upon the larger diameter of the seat only.

This modification is not necessary or even desirable with all types of valves and, in fact, no improvement has been found on a variety of valves. One would suggest that the shape of the valve head largely determines whether or not the modification is required. For instance, a " flat " headed valve might deform more than one of the " tulip " type and therefore should benefit by such a modification. If, however, one hits upon the correct angular difference for an appropriate valve, be it (the difference) one of 5′ or 30′, more or less, the benefit to the valve seat condition is most marked.

These experiments have, however, revealed the great importance of accurately machining and grinding valve seats and inserts, and how great are the variations in seat angles and condition when the valves are machined and then " lapped in " in the normal manner. For high duty engines, particularly, one would suggest that not only should the valve seat itself be accurately ground to close limits, but also that of the insert, after the latter is fitted. The valve should then be lightly lapped to the insert, sufficient to ensure that it shows a " marking " with a very small amount of Prussian blue.

Knock Testing and Assessing Fuels in Relation to Engine Performance

The question of testing fuels for anti-knock value is, admittedly, a subject in itself and hardly comes within the scope of this paper, but it is such an important one, with a direct bearing upon the successful development and satisfactory operation of aviation engines that perhaps little excuse is needed to mention it and one hopes to be forgiven for making a few remarks on the subject.

The whole essence of knock testing technique is the ability to correlate the results obtained on the fuel testing unit, with the performance of the fuels in the engine and to be able to assess the knock ratings of the various fuels in their order of merit.

It is exceedingly difficult to arrange a complete set of conditions for the fuel testing unit, which will imitate, accurately, those met with in the engine.

Some time ago the Institution of Petroleum Technologists appointed a sub-committee to formulate a suitable programme in order that experiments could be carried out and the data obtained therefrom used to enable a satisfactory technique to be evolved for the correlation of laboratory knock test results with actual engine performance.

Tribute should be paid to the I.P.T., which is the first body to formulate a method of knock testing and correlating aviation fuels to be accepted nationally. This should, however, only be regarded as a preliminary step.

These test results are very clearly and completely described by Pye, who was chairman of the sub-committee, in the paper referred to below.[10]

The running tests were carried out at the R.A.E., Farnborough, on air and water-cooled units and at the works of the Bristol Aeroplane Co. Aero Engine Section, Filton. In these particular tests, however, single-cylinder units of the representative Service engines were used and in no case was a complete engine employed, due, according to the report, to the " extreme difficulty of accurately detecting the onset of detonation in a complete aero engine and to the large quantity of expensive sub-standard fuel which would be required."

One submits that while useful data has been obtained as a result of these tests, it would have made the investigation of considerably greater value if some tests had been done on complete engines, if not with all the fuels investigated, at least with one or two spirits which are commonly used for the make-up of fuels in this country.

In addition, none of the fuels which were tested in the aviation engine cylinders contained lead. This is particularly significant since the Air Ministry has recently issued two fuel specifications, D.T.D. 224 and 230 (superseding D.T.D. 134), one of which, 230, allows the use of lead. Since the Ministry has adopted the laboratory knock testing method which has been evolved as a result of the I.P.T. investigation it is possible that there may be additional difficulty in obtaining correlation in the case of fuels to D.T.D. 230 specification, containing lead.

The author contends that, outside the expense and particularly in the case of the air-cooled engine, the question of audible detonation is not necessarily important, but that the temperature effects on the cylinder head, due to the detonative characteristics of the particular fuel used, are more a measure of that fuel's ability to operate satisfactorily in the engine.

It has been found, with these large engines of comparatively high specific power output, that a fuel can cause a dangerous rise in the operating temperature of the cylinder head which, on further increase, will result in pre-ignition rather than detonation. This is markedly so when the non-knocking fuels are used.

This is largely the reason why all the recent fuel specifications formulated by the U.S. Army Air Corps specify that the sample tested shall not show a higher reading of the temperature plug than the reference fuel; rather than taking bouncing pin readings.

One believes that there are yet some difficulties to overcome in using the " temperature rise " method as a laboratory test, and at the moment it is difficult to say whether it will take the place of the bouncing pin in the laboratory for general, or even particular, use.

The American firms literally " plaster " their engines with thermo-couples when investigating and trying out fuels, and nearly all engines sold are rated

[10] " The Knock-Rating of Aviation Fuels," by D. R. Pye. World Petroleum Congress, London, July, 1933. Standardisation Section.

on a fuel of specified anti-knock value, and the customers usually have to supply the manufacturers with a sample of the fuel on which they intend to run the engine. This sample is then tested in the complete engine, and so long as the cylinder head temperatures remain within the normal limits prescribed by the engine makers, the latter will pass it as fit and continue to give their service guarantee.

Reverting to the I.P.T. investigation, and with reference to the foregoing, one would say that one or two fuel tests carried out on a complete engine, particularly of the air-cooled type, heavily thermo-coupled at suitable points, would have yielded more valuable information than the single-cylinder tests, which are difficult to compare with those done on complete engines. A further important point is that the tests at Farnborough were run at varying speeds, whereas general experience would indicate that constant speed is necessary when matching fuels.

The report also gives an explanation for the test method finally adopted as a result of the work done, *i.e.*, C.F.R. Motor Method[11] modified to use a mixture temperature of 260°F., instead of 300°F., and why the method is less severe than that employed for correlating automobile fuels (Motor Method).

The explanation is " that when a road vehicle engine is pulling at low speed on full throttle the conditions are not only severe by reason of the low speed, but that in many types there is also provision for a large amount of mixture heating which may vary and exceed even the heating provided by a supercharger."

While one is of the opinion that the Motor Method of testing fuels still has certain snags, and does not necessarily apply to the types of British car engines on the road (American cars only were used for the tests done by the C.F.R. Committee), it is difficult to agree that the explanation given covers the case.

A road vehicle is certainly severe on the fuel under the conditions described, but it must be remembered that the B.M.E.P. and mean temperatures, when compared with those of an aviation engine, are in general not so high and also that the cylinders are not so large with, generally, a greater ratio of surface to volume than the aviation engine.

Consequently, audible knock may be severe for the comparatively short time that the vehicle engine is running under these conditions, but, due to the inherent design of the automobile engine, it will take a considerable time before detonation becomes great enough to build up excessive heat and/or bring about actual damage, although, admittedly, the performance of the engine, and consequently the vehicle, is impaired. It is not easy to see how these conditions can be more severe than, say, those of an air-cooled engine having large cylinders by comparison and running at full rated load in an aircraft under climbing conditions, where the rate of air flow over the cylinders is at a minimum and as altitude is increased, with a corresponding decrease in air density, the difficulty of dissipating heat from the cylinders is greater.

Actually, the operating speed of an automobile engine, under which detonation usually occurs is not always so low as might at first be supposed, when compared with the normal speed of an aviation engine, although it may be lower in proportion to the maximum speed in the former case.

In fact the C.F.R. roads tests showed that maximum knock occurred at road speeds varying from about 15 to 40 m.p.h., corresponding to crankshaft speeds of approximately 900 to 2,500 r.p.m. respectively.

The contentions put forward here are not in any way intended as a criticism of the accuracy of the I.P.T. investigation; this is far from the case, since the results of the tests have proved their own accuracy and have shown that it is possible to obtain good correlation with a given set of engine conditions.

The author's criticism is that the engine conditions, specified, do not accurately represent those met with in actual service, and, in addition, only fuels

[11] See Appendix III. for full description of C.F.R. Motor Method of Test.

of comparatively moderate knock ratings were tested. Whereas, for future engine development, the Air Ministry has already brought out a fuel specification, D.T.D. 230, in which an octane value of 87 is called for when tested under the modified Motor Method. This test is based on the results of the I.P.T. investigation.

This fuel will be used for new types, or future " marks " of present types of engines, produced by the manufacturing concerns. These engines will undoubtedly produce higher specific power outputs than the previous models, upon which the I.P.T. investigation was made, and will probably give the fuel a harder time in comparison.

It remains to be seen, therefore, whether the correlation, as carried out, applies in this particular case. Possibly it may do, and this is one of the peculiarities regarding the correlation of aviation fuels, although the subsequent matter applies more particularly to Service than to civil use. The Air Ministry issue the fuel specification in the first place, consequently the engine firms have some idea of the characteristics of the fuel before the development of their latest designs commences. Therefore, what it amounts to is this, they (the engine firms) obtain supplies of the fuel (in this particular case, 87 octane) and rate the new types up to their capabilities with this fuel.

It does not particularly concern the engine people how the fuel was assessed in the laboratory, so long as the laboratories of the various firms who supply the fuel under Air Ministry contract obtain correlation between themselves. This is, naturally, very important indeed, and is not easy to arrange. Therefore, those engines which by virtue of their design give the fuel an easier time of it, will naturally make greater use of any given fuel and show a higher rating than others not so fortunate in this respect.

The fact remains that, provided correlation between the *laboratory tests* of the various fuel suppliers can be obtained, each engine is developed to give the best optimum results with the fuel and correlation is automatically achieved.

To go one step further, the engine manufacturers might obtain samples of fuels to the D.T.D. 230 specification, from each fuel supplier contracting to the Air Ministry, and select the fuel which is the most sensitive to engine conditions and develop on that fuel so that the engine, when put into service, could be certain of giving its rated performance with safety on all fuel to this specification received from different sources of supply.

In this way a comprehensive correlation would be effected, at least for Air Ministry requirements.

One understands that some correlation tests on complete engines are already in progress in America, and it will be interesting to study the results and learn the conclusions arrived at, if and when they are published.

As a matter of interest, the latest fuel specification, No. Y-3557-G. evolved by the U.S. Army Air Corps, calls for a nominal octane value of 92.[12]

The method of knock testing this fuel has been completely revised. A C.F.R. engine is used as the basis, but is considerably modified to conform to Air Corps requirements. The temperature rise method of measuring the anti-detonation value of fuels is still retained. The engine speed of the unit has been considerably increased, and the test will be done at 1,200 r.p.m., with a jacket temperature 165°C. (330°F.).

The C.F.R. Committee, however, has tentatively adopted the C.F.R. Motor Method, unmodified, for testing aviation fuels, pending the results of the investigations they are now making concerning the most suitable method of test to be adopted in order to correlate laboratory results with performance of the fuel in the engine. The work of the C.F.R. Committee must not be confused with that of the U.S. Army Air Corps, which latter is an entirely separate and Governmental body.

[12] " Detonation Rating of Aviation Fuels," by H. K. Cummings. World Petroleum Congress, London, 1933.

The C.F.R. Committee is a body representing the oil concerns, also automobile and aviation engine interests.

Conclusion

In conclusion, it is hoped that this paper gives information which will be of direct use to those concerned with the design and development of aviation engines.

The author submits that he has given a fairly comprehensive exposition of the leaded fuel situation, and that this was needed in view of the lack of comprehensive and practical information which was available to the engine manufacturers and operators.

It is not too much to say that air supremacy, whether considered from the civil or military standpoint, will eventually go to the nation which develops engines making the fullest use of fuels of really high anti-knock value.

The use of tetraethyl lead is now generally accepted, and it is considered to be an essential constituent for fuels of high anti-knock value.

The author desires to record his thanks to the Ethyl Export Corporation for permission to present this paper and also for the very great assistance and advice given by Dr. Graham Edgar, Mr. S. D. Heron, Dr. F. H. Garner and Mr. E. L. Bass.

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APPENDIX I.

Octane Number

The anti-knock value of fuels for petrol engines is now usually assessed in terms of "octane number."

An explanation of this method of assessment is given herewith; petrol or gasoline are generic terms for the more volatile fuels, distilled from crude oil. Petrol and also the crude oil from which it is produced is a complex arrangement of hydrocarbons, *i.e.*, hydrogen and carbon in chemical combination.

Obviously with such a complicated make up, in which the various hydrocarbons and groups of hydrocarbons are involved, all of which react differently to any given set of conditions, it is difficult to test petrols even in a comparative manner.

The importance of obtaining a good reference fuel, a standard, against which petrols can be tested will, naturally, be appreciated and the search for suitable constituents proceeded for some time before anything was found.

Two excellent constituents were eventually found by Dr. Graham Edgar in the course of his researches, namely, iso-octane and normal heptane. These are pure hydrocarbons in themselves and have "constant" qualities.

Iso-octane has an anti-knock value higher than all ordinary petrols and normal heptane has pro-knock qualities worse than most petrols.

The octane number of a petrol is, numerically, the percentage by volume, of iso-octane in a mixture of iso-octane and normal heptane which matches the fuel tested in anti-knock or "detonation" value. 100 per cent. of iso-octane is equal to an octane number of 100, and 100 per cent. normal heptane equals an octane number of 0.

Therefore, if a mixture of 87 per cent. octane and 13 per cent. heptane is required in order to give the same reading as a fuel, when both are tested under the same conditions in a knock-testing engine, that fuel will be said to have an octane number of 87.

Unfortunately, octane and heptane are exceedingly costly to produce, so that "sub-standard" reference fuels are generally used for routine testing. These consist of certain "cuts" of straight run petrols which have known characteristics, and the octane numbers required are obtained by the addition of benzene (a constituent of benzole) or tetraethyl lead.

These sub-standards are carefully stored to avoid any changes in quality, and they are periodically checked against actual mixtures of octane and heptane.

It is the custom to quote the type of test engine and the conditions of test under which an octane number has been ascertained because of the behaviour of petrols under varying conditions of test. It is very important, to those dealing with questions of fuel quality, to know the exact conditions of testing in order that some degree of correlation may be obtained between test results and the actual performance of the fuel in the engine

APPENDIX II.

Air Ministry Material Specification No. D.T.D.230 for 87 Octane Standard Fuel for Aero Engines

1. *Description*

The standard fuel for aero engines shall consist of high grade petrol prepared from crude petroleum, coal spirit or mixtures thereof.

The fuel as a whole shall be neutral, clear, free from undissolved water, and any suspended matter.

In order to obtain the necessary anti-detonation value as specified in Clause 8, it is permissible to add aromatic hydrocarbons and/or tetraethyl lead in the form of 1T ethyl fluid in concentrations not exceeding 4 mls. of tetraethyl lead per imperial gallon.

The extent of such additions will be governed by the succeeding clauses of this specification.

2. *Distillation Range*

When 100 mls. of the fuel submitted are distilled in the standard distillation apparatus, they shall distil at 760 mm. pressure:—

Below 75°C. not less than 10%
At 100°C. ,, ,, ,, 50%
,, 150°C. ,, ,, ,, 90%
The end point shall not exceed 180°C.
The distillation loss shall not exceed 2%.
The total volume of distillate collected in the receiver shall not be less than 96%.

3. *Vapour Pressure*

The vapour pressure as determined by the Reid method at 37.8°C. (100°F.) shall not exceed 7lbs. per sq. inch.

4. *Specific Gravity*

The specific gravity at 15°C. shall be not more than 0.79.

5. *Sulphur Content*

There shall be a complete absence of free sulphur when determined by the copper strip method and the total sulphur content shall not exceed 0.15 per cent. by weight.

6. *Freezing Point*

The freezing point as indicated by the initial formation of solid shall be not higher than minus 60°C.

7. *Gum*

(*a*) *Existent Gum.* The amount of existent gum as determined by the evaporative method in a glass dish shall not exceed 10 mgms. per 100 ml.

(*b*) *Potential Gum.* After 50 mls. of the fuel have been incubated at 35°C. for 20 hours, the increase of gum yield over and above the existent gum as determined by the evaporative glass dish method shall not exceed 10 mgms. per 100 ml. (For method of determination of gum, see Appendix I.)

8. *Anti-Detonation Value*

The anti-detonation value shall be not less than 87 octane number when determined by the standard "C.F.R. Motor Method" modified so that the unit is run with a mixture temperature of 260°F.

The octane number is numerically the percentage by volume of iso-octane (2, 2, 4 trimethyl pentane) in a mixture of iso-octane and normal heptane. The octane number of the fuel is the octane number of the mixture of iso-octane and normal heptane which it matches in anti-detonation value.

A secondary or sub-standard reference fuel may be used for purposes of matching, but the sub-standard fuel must be equal in knock rating to the primary octane-heptane mixture when tested under the conditions specified. Supplies of standard or sub-standard fuels will not be issued by the Air Ministry. The Air Ministry will use as a sub-standard, a straight run petrol of high knock rating with the addition of pure crystallisable benzene when undoped fuels are being tested and the addition of T.E.L. when fuels containing T.E.L. are being tested.

(Note.—Three comparisons of the sample with the reference fuel are to be made. The sample on the average of these comparisons shall not be inferior to the standard. Frequent calibrations of the secondary reference fuels against the primary octane-heptane standard must be made).

9. *Colour*

When tetraethyl lead is used as an anti-detonant, the fuel must be coloured noticeably blue with a suitable dye to distinguish the leaded fuel from those not so doped.

10. *Methods of Test*

Except where otherwise stated the "Standard Methods of Testing Petroleum and its Products," Second Edition, and such Addenda as may be promulgated by the Institution of Petroleum Technologists will be used. The required tests are enumerated in Appendices 1 and 2.

11. *Sampling*

Normal I.P.T. methods of sampling are to be adopted; but in cases of dispute, particularly in connection with gum tests, it is essential that sampling should be carried out in accordance with the details laid down in Appendix III.

APPENDICES TO D.T.D.230

APPENDIX 1.

Gum Tests—Description

Apparatus

The apparatus shall consist of the following:—

(*a*) *Dish.* The dish shall be made of a suitable resistance glass and in shape shall be either hemispherical, 80 to 90 mm. in diameter, or flat-bottomed, 80 to 90 mm. in diameter at the top, 45 to 50 mm. in depth, and approximately 45 mm. in diameter at the bottom.

(*b*) *Steam Bath.* The apertures shall be of such size that the dishes will be immersed to within about 10 mm. of the top. If the evaporation is not carried out in a draught-free chamber, the bath shall be provided with a draught shield.

(*c*) *Storage Flask.* A 500 ml. measuring flask fitted with a glass stopper, and made of a suitable resistance glass, shall be used.

Procedure

Existent Gum. 50 ml. of the petrol shall be evaporated in the glass dish on a vigorously-boiling steam bath, the dish having been cleaned previously by soaking in chromic-acid solution, and rinsing in distilled water.

After the evaporation, the outside of the dish shall be wiped dry; the dish shall then be transferred to an oven maintained at 150°C. and allowed to remain there for one hour. After cooling in a dust-free place for 20 minutes, the dish shall be weighed by tare, against another similar dish which has been treated similarly but without the petrol, to an accuracy of ± 0.1 mgm. The operations after heating the dish shall be made with the use of metal forceps.

Potential Gum. 50 ml. of the petrol contained in the glass-stoppered glass flask shall be incubated at 35°C. in the dark for 20 hours. At the end of that time, the contents of the flask, together with acetone rinsings obtained by swilling out the emptied flask with a little re-distilled acetone, shall be transferred to the glass dish described in the previous test, and the amount of gum formed determined by the evaporative method described previously.

APPENDIX II.

Schedule of Standard—I.P.T. Tests

Specific Gravity	G.1
Distillation	G.3
*Total Sulphur	G.4 (A.S.T.M. D.90-30T)
*Free Sulphur	G.4B. (A.S.T.M. D.130-30)
*Vapour Pressure	G.37 (A.S.T.M. D.323-32T)
*Normal Sampling	I.P.T. (A.S.T.M. D.270-30T)
*Determination of Tetraethyl Lead ...	G.38 (Edgar & Calingaert)
*Anti-Detonation Value	G.39 (A.S.T.M. D.357-33T)

*NOTE.—These tests are either under consideration or revision by the Institution of Petroleum Technologists and pending the issue of the I.P.T. addenda concerned the equivalent A.S.T.M. methods or alternative methods enumerated may be used.

APPENDIX III.

Method of Sampling for Gum Tests

It is important that the following precautions be taken in sampling in order to avoid the introduction of extraneous matter which might cause erratic gumming.

(*a*) The bottles, preferably narrow-necked and glass-stoppered, should be washed in chromic-acid solution, then rinsed with distilled water, and dried.

(*b*) If corks are used, these should be new and extracted with acetone and preferably wrapped around with tin or lead foil.

(*c*) The glass dipper, or syphon, etc., used for removing the sample from the container, should be frequently rinsed with acetone and dried in order to remove any gum.

(*d*) The sample bottle should be filled to the neck.

(*e*) Wrapped or packed in a light-proof container.

(*f*) Stored in a cool place until required for analysis.

APPENDIX III.

The C.F.R. Motor Method for Knock Determination

Details of A.S.T.M. Standard for Evaluating Motor Fuels

The American Society for Testing Materials has now issued details of the tentative method of test for knock characteristics of motor fuels. It is now accepted as a tentative standard and criticism and suggestions are solicited. This method, heretofore known as the C.F.R. motor method, is intended for determining the knock characteristics, in terms of an arbitrary scale of octane numbers, of gasolines and equivalent fuels for use in spark-ignition engines, other than engines for aircraft.

The A.S.T.M. octane number of a motor fuel is the whole number nearest to the octane number of that mixture of iso-octane with normal heptane which the motor fuel matches in knock characteristics when compared by the procedure specified herein.

Octane number is defined by and is numerically equal to the percentage by volume of iso-octane (2, 2, 4 trimethylpentane) in a mixture of iso-octane and normal heptane, used as a primary standard for measurement of knock characteristics. Thus, by definition, normal heptane has an octane number of zero and iso-octane of 100.

Apparatus

The knock-testing unit described in this section, known as the "C.F.R. engine," shall be used without modification. The apparatus shall consist of a continuously variable compression motor together with suitable loading and accessory equipment as follows:—

(*a*) *Engine.*—Continuously-variable-compression, one-cylinder, with dimensions as follows: Bore, 3.25in.; stroke, 4.50in.; displacement, 37.4 cub. in.; valve diameter, clear, 1.1875in.;

connecting-rod bearing, diameter 2.25in., length 1.625in.; front main bearing, diameter 2.25in., length 2in.; rear main bearing, diameter 2.25in., length 4.25in.; piston pin, floating, diameter 1.25in.; connecting rod, centre to centre, 10in.; timing gear face, 1in.; piston rings, number, 5; exhaust pipe, diameter, 1.25in.; spark plug, size, 18 mm.; weight of engine (approximate), 475lb.; weight of complete unit (approximate), 1,375lb.

(*b*) *Crankshaft.*—Fully machined, heat-treated and counter-balanced.

(*c*) *Crankcase.*—Cast iron, with rigid end walls.

(*d*) *Connecting Rod.*—Rifle-drilled, S.A.E. No. 1,045 steel, heat-treated, bearing alloy cast directly into big end.

(*e*) *Main Bearings.*—Renewable sleeve bushings, babbitt-lined.

(*f*) *Valves.*—Silcrome. Inlet valve with specially designed shroud.

(*g*) *Push Rods.*—Mushroom type with lock-nut adjustment.

(*h*) *Cylinders.*—Cast of iron alloy, bored and honed, Brinell hardness, 200 to 210.

(*i*) *Cylinder Head.*—Integral with cylinder.

(*j*) *Cooling System.*—Evaporatively cooled.

(*k*) *Lubrication.*—Pressure feed to main connecting-rod, piston-pin, and camshaft bearings, and to idler gear stud and gears.

(*l*) *Oil Heater.*—Electric heater in base to bring oil to operating temperature quickly.

(*m*) *Ignition.*—May be either a battery system or a magneto. A neon-tube spark indicator is built into the engine. Spark advance is automatically adjusted as the compression ratio is changed.

(*n*) *Carburettor.*—A special C.F.R. carburettor is furnished with the engine, and can be obtained with either two or four float bowls. The carburettor has a fixed fuel jet, shrouded by a variable air jet. Fuel containers are furnished with the carburettor.

(*o*) *Mixture Heater.*—As supplied by manufacturer, consisting of (1) a manifold, (2) an electric immersion heater and rheostat for controlling mixture temperature, and (3) a special mercury stem thermometer, 100 to 400°F. (38 to 204°C.), so mounted that the bulb is centred in the mixture stream to indicate the mixture temperature.

(*p*) *Instruments.*—Knock intensity is measured by a bouncing pin, in conjunction with either a knockmeter or a gas-evolution burette. Current is supplied from a small direct-current generator, belt driven from the power-absorbing unit. The knockmeter is a damped hot-wire ammeter which indicates the effective current in the circuit, thus permitting instantaneous readings. The gas-evolution burette is an electrolytic cell which integrates the impulses of current through the bouncing-pin circuit and indicates the total by the volume of gas collected in the burette in a given time.

(*q*) *Power-absorbing Unit.*—The engine is connected by V-type belts to an electric generator. This preferably should be an induction motor with synchronous characteristics but may be any electric generator capable of maintaining proper operating conditions. In most cases the electric generator will act as a starting motor to crank the engine, but if a direct-current generator is used and no outside source of current is available, the engine may have to be cranked by hand.

(*r*) *Complete Unit.*—The complete unit may be obtained with the engine, generator and panel board mounted on a cast-iron base plate. All necessary instruments and accessories are furnished with the unit.

Reference Fuels

Primary Reference Fuels.—The primary reference fuels shall be iso-octane (2, 2, 4 trimethylpentane), and normal heptane. Both shall be certified for suitability as primary reference fuels by the United States Bureau of Standards.

Secondary Reference Fuels.—Mixtures of normal heptane and iso-octane required for referee testing are expensive. For this reason secondary reference fuels may be used for routine determinations. Such secondary reference fuels may be straight-run or other stable gasolines suitable for the purpose. One of the reference fuels should be of low knock-rating and the other of high knock-rating, or if a sufficiently high knock-rating fuel is not available, a mixture of the higher knock-rating fuel plus a knock suppressor may be used. These secondary reference fuels shall be calibrated on the octane number scale against normal heptane and iso-octane sufficiently often to ensure accuracy of calibration; and for every case, whether a fuel is rated by secondary reference fuels or by means of normal heptane and iso-octane, the result shall be recorded as an octane number.

For the present this certification consists of tests made by the Bureau of Standards on each batch of normal heptane or iso-octane prepared respectively by the two companies mentioned, with certificates issued to these companies authorising them to guarantee to

the purchaser that the material shipped is part of a batch so tested and to quote the results of the Bureau of Standards tests.

Standard Operating Conditions

The engine shall be run under the following standard conditions:—

(*a*) *Engine Speed.*—900 r.p.m. ±3 r.p.m.

(*b*) *Jacket Temperature.*—Constant within ±1°F. (0.6°C.) and at a temperature between the limits of 205 and 215°F. (96 and 102°C.).

(*c*) *Cooling Liquid.*—Distilled water, rain water, or ethylene-glycol solution when necessary at high altitude.

(*d*) *Crankcase Lubricating Oil.*—S.A.E. 30.

The viscosity range of crankcase lubricating oil, S.A.E. 30, is from 185 to 255 seconds when determined on the Saybolt Universal viscosimeter at 130°F. (54.4°C.), in accordance with the standard method of test for viscosity of petroleum products and lubricants (A.S.T.M. designation: D88) of the American Society for Testing Materials.

(*e*) *Oil Pressure.*—25 to 30lb. per sq. in. under operating conditions.

(*f*) *Valve Clearances.*—Intake 0.008in., cold; exhaust 0.010in., cold.

(*g*) *Spark Advance.*—Automatically controlled: 26° at 5:1 compression ratio (basic setting); 22° at 6:1 compression ratio; 19° at 7:1 compression ratio.

(*h*) *Breaker-point Clearance.*—Battery system 0.015in.; magneto 0.020in.

(*i*) *Spark Plug.*—Shall conform to the standard metric plug having the tolerances and thermal characteristics equal to the No. 8 spark plug furnished by the Champion Spark Plug Company, Toledo, Ohio. Gap setting, 0.025in.

(*j*) *Throttle Opening.*—All tests shall be conducted with the throttle opening at the point of maximum volumetric efficiency, approximately 90 on the throttle scale.

(*k*) *Carburettor Adjustment.*—For maximum knock.

(*l*) *Exhaust Pipe.*—A separate exhaust pipe should be used for each engine. This pipe should be made from $1\frac{1}{4}$in. pipe having a maximum of two ells with a total length not to exceed 20ft. The use of a short straight-through muffler of $1\frac{1}{4}$in. diameter passage for prevention of noise is permissible.

(*m*) *Mixture Temperature.*—The mixture temperature shall be maintained at 300°F. ±2°F. (149°C. ±1.1°C.) as indicated by the mercury stem thermometer.

(*n*) *Bouncing-pin Assembly.*—The gap setting shall be 0.003in. to 0.005in.

The following instructions for setting of the bouncing-pin contacts should be used: With the daily inspection, observe the contact points and electrical connections to see that the points are smooth and that all the connections are tight. The gap setting should be checked (0.003in. to 0.005in.). The flat spring of the lower contact should touch the insulated pin with slight pressure. Too much pressure will reduce its sensitivity. To adjust the pressure accurately, set the points with 0.003in. to 0.005in. clearance. Then remove the diaphragm and bouncing pin. Bend the lower spring until there is from $\frac{3}{64}$in. to $\frac{1}{16}$in. gap between the points. Remove the upper stop-adjusting screw and bend the upper spring until there is $\frac{5}{32}$in. gap between the points. Check the tension on the small plunger spring in upper stop-adjusting screw and see that it has from 1 to $1\frac{1}{4}$lb. initial tension. This can be measured by pressing it against any convenient platform scale. The pin should then be re-assembled and the adjusting screw set to give 0.003in. to 0.005in. gap between the points. The final adjustment is made by setting the clearance so that a knockmeter reading between 50 and 60 is obtained when operating the engine at the proper knock intensity.

Procedure

Starting and Stopping the Engine

While the engine is being turned over by electric motor the ignition shall be turned on and the carburettor set so as to draw fuel from one float bowl. To stop the engine the fuel and the ignition switch shall be turned off and then the motor shall be stopped by means of the push-button switch. To avoid corrosion of valves and seats between operating periods the engine should be turned over by hand until both valves are closed

Preliminary Adjustment of Compression Ratio

Using a mixture of 65 parts of iso-octane and 35 parts of normal heptane, the compression ratio for first audible knock shall be obtained by increasing the compression ratio, by increments of two turns of the crank, from a point where there is no knock to the compression ratio at which audible knock is first detected. The proper knock intensity for use in making knock ratings shall be the knock intensity obtained with the mixture

of 65 parts of iso-octane and 35 parts of normal heptane when the compression ratio is increased one unit over that compression ratio giving first audible knock. Then the numerical indication of knock intensity obtained from the knockmeter or from the gas-evolution burette, whichever is used, shall be recorded. This procedure is necessary for the first adjustment only.

This knock intensity should be equivalent to the intensity obtained with a mixture of 65 per cent. of iso-octane and 35 per cent. of normal heptane at a compression ratio of 5.3 $\pm$0.05 to 1 when testing at a barometric pressure of 760 mm.

For subsequent tests on fuel samples the compression ratio shall be set to duplicate this knock intensity, as indicated by the knockmeter or the gas-evolution burette provided no change has been made in the bouncing-pin adjustment in the meantime. In no case shall the knock intensity be such that the engine does not cease firing when ignition is interrupted.

Outline of Procedure

The octane number of a fuel shall be ascertained by comparing the knock intensity for the fuel with those for various blends of the reference fuels until two blends differing in knock-rating by not more than two octane numbers are found, one of which gives a higher knock intensity than the fuel and the other a lower knock intensity. The knock intensity shall be measured by a bouncing-pin indicator in conjunction with either a knockmeter or a gas-evolution burette.

Before the test sample and the blends of the reference fuels can be compared, the compression ratio must be set to give the proper knock intensity and the carburettor adjusted to give the maximum knock for each fuel.

Adjustment of Carburettor for Fuel under Test

Using the fuel whose knock-rating is to be determined the carburettor shall be adjusted as follows: After one float bowl of the carburettor has been filled with the fuel of which the octane number is to be determined, adjustment shall be made to obtain maximum knock by noting the needle valve micrometer setting and the knockmeter reading or gas evolution, then turning the micrometer screw and noting whether the knockmeter reading or gas evolution increases or decreases. The micrometer shall then be turned in the direction in which the knock increases until the knock passes through a maximum. This point shall be checked three times and the micrometer set at the position of maximum knock.

(*a*) *By Knockmeter.*—When using the knockmeter, it is unnecessary to take readings over a fixed period of time, but the knockmeter needle shall be allowed to reach equilibrium after each adjustment of the micrometer.

(*b*) *By Gas-evolution Burette.*—At least two readings, agreeing within 5 per cent., of the volume of gas evolved over a period of 1 minute shall be taken as a measure of knock intensity.

Final Adjustment of Compression Ratio

Finally, adjust the compression ratio to give the same reading on the knockmeter or gas-evolution burette when using the fuel under test as was obtained in the first adjustment.

A trial blend of the low octane number reference fuel and the high octane number reference fuel, based on the expected knock-rating of the fuel sample under test, shall be placed in another carburettor float bowl and the engine run on this trial blend. The micrometer of this float bowl shall then be adjusted to the maximum knock position in a manner similar to that described.

Octane Number Determination

With the carburettor micrometers set for the air-fuel ratio of maximum knock, alternate series of readings of knock intensity shall be taken on the fuel under test and on a reference fuel blend. When using the knockmeter, the needle shall be allowed to reach equilibrium before the final reading is recorded. When using the gas-evolution burette, at least two successive 1-minute readings shall agree within 5 per cent.

At least three alternate series of readings shall be taken on each fuel. After changing from one fuel to another, at least one minute shall be allowed for the engine to reach equilibrium. With some fuels an appreciably longer time interval may be required. If the average knock intensity of the fuel sample is higher than the average of the reference fuel blend, the test shall be repeated with a blend containing a decreased proportion of

the high octane number reference fuel. The test shall be continued in this manner until the knock intensity for the fuel sample is definitely higher than one blend and lower than another blend of the reference fuels. The difference between these two final reference fuel blends shall be not more than two octane numbers.

Calculation

The knock-rating of the fuel sample shall be obtained by interpolation from the figures so recorded and the nearest whole number shall be reported as A.S.T.M. octane number.

Check of Test Conditions

Test conditions shall not be regarded as standard unless a blend by volume of 65 per cent. iso-octane and 35 per cent. normal heptane is matched under the specified procedure by a blend by volume of 68 ±1 per cent. one degree benzene with 32 ±1 per cent. normal heptane. At atmospheric pressure of 760 mm. a compression ratio of approximately 5.3:1 is correct for this determination. Substantial variations in atmospheric pressure will change the compression ratio required.

For routine checking purposes, one degree benzene and secondary reference fuels may be used.

" One degree " benzene is a commercial product conforming to the following requirements:—

(*a*) Boiling range not greater than 1°C., embracing the boiling point of chemically pure benzene.

(*b*) Specific gravity of from 0.882 to 0.886, when determined in accordance with the tentative method of test for gravity of petroleum and petroleum products by means of the hydrometer (D287-32T) of the American Society for Testing Materials.

(*c*) Free from hydrogen sulfide, carbon disulfide and thiophene.

(*d*) Free from turbidity, with colour not darker than a solution of 3 mg. of potassium dichromate in 1 litre of water when compared in 50 cc. Nessler tubes.

Accuracy

Results obtained by this procedure with different C.F.R. engines and in different laboratories should differ by not more than two octane numbers.

While the accuracy of this method is as above stated, its sensitivity may permit detection of differences as small as 0.2 octane number when alternate readings of knock intensity are taken on the two fuels as directed.

APPENDIX IV.

Haynes Stelliting Wearing Surfaces—Oxy-acetylene Process

Haynes Stelliting means depositing a layer of Haynes Stellite on metal wearing surfaces. It increases the life of wearing parts from three to five times. It can easily be done in your own shop with the oxy-acetylene blowpipe as described below.

1. Prepare the surface by grinding, machining, chipping or filing the base metal till clean and free from oxide and scale. Do not leave sharp corners when preparing the metal for Haynes Stelliting.

2. Preheating is often necessary and may be done with a neutral oxy-acetylene flame or in a furnace. Preheating helps to prevent cracks in the deposited metal.

3. The flame for Haynes Stelliting must contain an excess of acetylene. Note the two inner cones shown in the photograph below, and adjust the flame to about the same proportions. This is very important and must be done to insure a satisfactory job.

4. If the base metal is steel, do not actually melt it, but bring a small area at a time to a sweating heat. Then bring the end of the Haynes Stellite rod into the flame and melt the metal on to the sweating surface of the steel. If the steel is at the sweating heat and the flame is properly adjusted, the Haynes Stellite will flow and spread like

solder on a tinned surface. If the Haynes Stellite is forced to spread by being poked with the rod, the junction will not be as strong as if the metal were allowed to flow by itself. It is usually possible and preferable to build the coating to the desired thickness in one operation.

If the base metal is cast iron it will not sweat like steel and a little less acetylene should be used in the flame than for steel. Haynes Stellite does not flow as readily on cast iron as on steel, and it is usually necessary to break the surface crust with the end of the rod. A cast iron welding flux is sometimes necessary. It is usually best to weld in a thin coating of Haynes Stellite first and then go over it again and build up to the desired thickness. Haynes Stellite and cast iron have about the same melting point, hence care must be taken not to melt the base metal too deeply. If the cast iron is very thin it will be helpful to back it up with wet asbestos or carbon paste to avoid melting it.

5. All specks of scale and oxide should be floated, as they cause holes if left in the metal. Another cause of pin holes is a flame that does not contain enough excess acetylene.

6. Avoid puddling and penetration as this dilutes the Haynes Stellite with iron and lowers its resistance to abrasive wear.

7. Use the same cooling procedure as in ordinary welding, bearing in mind that No. 1 Haynes Stellite has practically no ductility. It is usually unnecessary to heat treat a Haynes Stellited part, but if the steel base must be toughened, quench in oil—not water.

8. Haynes Stellite, when properly applied, will never break loose from the base metal. Cracks on the surface usually run through the Haynes Stellite and stop at the steel or iron base. Such cracks are not detrimental to most applications encountering abrasive wear or hard blows.

9. All kinds of steel can be Haynes Stellited by the oxy-acetylene process with the exception of high manganese (Hadfield) and high speed steel. Monel metal is easy to Haynes Stellite; copper is very difficult; brass and other low melting alloys cannot be Haynes Stellited.

Haynes Stelliting may also be done by the metallic arc process if a less perfect deposit is satisfactory. This process is always recommended for Haynes Stelliting manganese steel.

Haynes Stellite cannot be machined, drilled, sawed or filed, but must be finished by grinding. Recommended wheels are listed below.

Recommended Wheels for Grinding Haynes Stellited Surfaces

HAND GRINDING

Rough Grinding Snagging, Etc. Portable	Carborundum Co. 46N Aloxite Vitrified Detroit-Star 46M Staralox Vitrified Norton 46M Alundum Vitrified Precision 46M Vitrified Sterling 46M Vitrified

MACHINE GRINDING

Cylindrical	Carborundum Co. 24P Vitrified Detroit-Star 24CK Staralox Vitrified Norton 24CK Alundum Vitrified Precision 24CK Vitrified
Internal (Holes 1in. or less)	Detroit-Star 44-80K Staralox Vitrified Norton 1980K Alundum Vitrified Precision 80J Vitrified
Internal (Holes 1in. to 2in.)	Detroit-Star 44-80J Staralox Vitrified Norton 1980J Alundum Vitrified Precision 6030L Vitrified
Internal (Large Holes)	Carborundum Co. 36R Aloxite Vitrified Detroit-Star 46I Staralox Vitrified Norton 46I Alundum Vitrified Precision 46I Vitrified

Appendix V.

Ethyl Gasoline Corporation Research Laboratory, Detroit, Mich. Report No. A.R.I.

The Suppression of Cylinder Bore and Valve Rusting in Aircraft Engines (Preliminary Report)

I. Summary.

Aircraft engines which have been operated on Ethyl Gasoline show a tendency to rust cylinder bores in storage or when operation is very intermittent. Exhaust valves may or may not rust, depending upon the material used and the extent of lubrication. Some exhaust valves are totally free of rusting even when operated and stored entirely without oiling.

The use of castor oil plus small additions of commercial triethanolamine has been found by the U.S. Army Air Corps to completely suppress rusting of any steel or iron surface to which it is applied.

Specific phases of rusting or cold corrosion in aircraft engines will be dealt with fully in a later report.

II. Introduction.

The use of Ethyl Gasoline in aircraft engines requires certain precautions if rusting of parts of the cylinder unit is to be prevented when the engine is subsequently stored or if operation is exceedingly intermittent.

Exhaust valve stem rusting with resultant sticking is probably the most serious result of cold corrosion. This corrosion occurs only with the martensitic valve steels (*e.g.*, Cobalt-Chrome, Silchrome and the chrome tungsten silicon types such as 12 per cent. Cr, 4 per cent. W, 2 per cent. Si). Continuous lubrication with such valve steels will almost completely suppress valve stem rusting in the great majority of cases. The austenitic nickel chromium steels, even when entirely unlubricated (open valve gear), are entirely immune from rusting.

Cylinder bore rusting is at times alarming to look at, but its effects are much less serious than visual inspection would suggest. An engine with badly rusted cylinders may be operated for a short period and on removal of the cylinders no evidence of damage to either cylinder bore or piston bearing surface will be found unless corrosion has proceeded to the extent of deep pitting of the bores.

The rusting is invariably associated with moisture which forms dilute acids. Prevention of such rusting appears to be simply obtained by means of one of or all three of the following: Solution, emulsification, or neutralisation of the dilute acids in or by a suitable oily mixture.

III. Corrosion Prevention Compounds.

As corrosion is always associated with moisture and dilute acids it would appear that solution of; emulsification of; or neutralisation in; or by a suitable oily mixture would be an answer. Whatever is the real mechanism of corrosion prevention an oily mixture which will do all or any of the above three has proved to be an answer to rusting.

Fatty oils in general have been found to be better rust-preventatives than the mineral oils. Certain mineral oils as a result of acid treatment or the use of chloro compounds in refining are notably poor as corrosion preventatives when applied in thin films and exposed to considerable quantities of water vapor.

Fatty oils in general will dissolve more water and form much more stable emulsions with water than will the normal engine mineral oils, and probably owe their superior rust-preventative power to these properties.

In addition to the property of dissolving or emulsifying dilute acids a rust-preventative should also embody an acid neutralising acid. An organic base appears to be a most desirable neutralising agent. Mineral alkalies obviously are undesirable, as on combustion resulting from engine operation they leave solid residues which will attack aluminium engine parts.

While it has not to the present been proved, it appears that completely water soluble organic base is the most effective. That this should be so is not unreasonable, as the acids to be neutralised are in very dilute water solution. Further, if the organic base is highly hygroscopic its admixture with the dilute acid should be facilitated. The base used, in addition, should show no tendency to attack steel, high copper alloys, or aluminium alloys, Aniline, ammonia, and aliphatic amines, for example, attack copper, and may produce rusting of steel.

The organic base, in addition, should be practically non-toxic and fairly high boiling, so that it will not be lost by evaporation from the oil, and should have an inoffensive odour.

Castor oil plus 2 per cent. commercial triethanolamine has been used very successfully

by the U.S. Army Air Corps as a corrosion preventative. Castor oil is a good engine lubricant except for its piston ring sticking properties, so that the small amount left in the cylinders when the engine is operated with its normal mineral oil lubricant is not likely to cause difficulty. Triethanolamine has all the properties required in the above discussion of a desirable organic base. When diluted with water it does attack aluminium at high temperatures, but the above-mentioned mixture has proven in practice entirely inert.

Service tests by the Air Corps have shown that castor oil plus 2 per cent. triethanolamine is superior to mineral engine oil containing an aliphatic amine, and this observation has been confirmed in this laboratory.

IV. Triethanolamine.

The commercial triethanolamine used by the Air Corps has been obtained from the Carbide and Carbon Chemicals Corporation. It costs about **$3.50** per U.S. gallon. Composition and properties[1] are as follows:—

75% Triethanolamine.
18% Diethanolamine.
7% Monoethanolamine.
Boiling Points: Triethanolamine 277°C. at 150 mm.
Monoethanolamine 171°C. at 760 mm.

All three of the above amines are highly hygroscopic.

The slight ammoniacal odour of commercial triethanolamine is not objectionable and it is non-toxic as regards application of the concentrated material to the skin.[2]

V. Castor Oil.

The castor oil used to date for blending with triethanolamine has been the U.S. Pharmaceutical Grade (cold pressed). There is no evidence that a cheaper grade cannot be used as long as the hot pressed grades which show pronounced piston ring sticking and gumming tendencies are avoided.

VI. Preparation of Castor Oil-Triethanolamine Blends.

The blends used to date by the Air Corps have been prepared by steam heating the castor oil to 250°F. approximately (125°C.) and vigorously stirring the triethanolamine into solution.

Commercial triethanolamine is soluble to the extent of approximately 10 per cent. in cold pressed castor oil at room temperature.

VII. Application of Castor Oil-Triethanolamine Mixture to Cylinder Unit.

The castor oil-triethanolamine blends to date have been applied almost entirely by setting the engine up so that the anti-rusting mixture will not run out of the intake or exhaust ports, and applying a considerable quantity of the material to the inside of the cylinder while the crankshaft is very slowly revolved. The pistons are moved over the full extent of their working stroke while applying the material, in order to work the oil thoroughly over the whole bearing surface of the cylinder bore and particularly between the piston skirts and cylinder bores. (There is considerable evidence that much cylinder corrosion is due to sweat from the piston skirts or moisture trapped between the skirts and the cylinder bores).

The above method of application is decidedly complicated and unnecessarily inconvenient. Spraying by means of a special nozzle inserted through a spark plug hole while the engine is slowly pulled over is now being investigated, and promising results have been obtained. It is expected that a suitable small and portable spraying device will be shortly available. With such a device it would seem that anti-rusting mixtures can be applied not merely to engines which are to be stored but also to those installed in airplanes and which are to be out of use for periods exceeding about seven days.

VIII. Discussion.

Successful rust prevention to date indicates that the anti-rusting mixture should have the following properties:—

(*a*) It should be fluid and have free flowing properties at room temperature, and should show a pronounced tendency to creep over metal surfaces at room temperature.

(*b*) It should emulsify or dissolve water or dilute mineral acids much more readily than normal mineral engine lubricating oil.

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[1] "Synthetic Organic Chemicals." Published by Carbide and Carbon Chemicals Corporation, 30E., 42nd Street, New York, N.Y.

[2] Dr. R. A. Kehoe—Private communication.

(*c*) It should contain a free organic base.
(*d*) The mixture either alone or in the presence of water should not attack steel of any kind, aluminium alloys, or high copper alloys.

Greases even of the low melting point type do not appear to adequately protect against rust.

The methods dealt with in this report are almost entirely those developed by the U.S. Army Air Corps, who have kindly consented to their release for general use.

February, 1934, S. D. HERON.

DISCUSSION

The CHAIRMAN: Mr. Banks had very wisely shortened his paper for the purpose of reading it to the meeting, but what he had said was quite enough to show what a very comprehensive paper it was, and it deserved the most careful study. There were a great number of points of interest to everybody who was engaged in this kind of engine development, and he thought the type of discussion that would be most helpful would be to have the experience of as many as possible of those who had been in charge of experimental work on engines using fuels containing tetraethyl lead. The paper contained a mass of information and a considerable number of, to some extent, controversial points. He himself could find very little to criticise in the lecture, but there was one point on which he might appropriately say a few words, namely, with regard to the knock-testing work which was done under the auspices of the sub-committee of the Institution of Petroleum Technologists, of which the speaker himself was chairman. Mr. Banks was perfectly right, of course, in saying that the scope of that work, judged by the results which had so far been published, was rather limited. It had been necessary to have a report available in time for the World Petroleum Congress which had been organised by the I.P.T., and in order to do so the scope of the report had been limited to non-leaded fuels of qualities generally representative of those commercially available 18 months ago, when the work was first planned. It was always intended that the work would be continued, and already a programme had been laid down which covered leaded fuels, brought up to an octane number of 87. By using different basic fuels, this octane number would be reached, in the test samples, when employing a wide range of different concentrations of lead, going beyond that which was covered by the D.T.D. specification, that is to say, " 4 c.c." fuel. Probably the test samples would go up to " 7 c.c." of lead.

An interesting point which Mr. Banks had criticised was the use of only single-cylinder engines. In the further series of tests that the sub-committee intended to carry out it would, he hoped, be possible to do some tests towards the end of the series on two or three fuels running on complete engines, and using thermocouples as Mr. Banks had suggested. The use of the " temperature plug " which he had mentioned was at the present time being looked into at Farnborough as a method of detecting detonation, and he thought it was possible that in due course the temperature plug might be developed to the point of being a more satisfactory method of detecting detonation than the bouncing pin. There were, however, many points which called for consideration, and the matter was not very clear at present. He did not feel certain that the Americans themselves were perfectly satisfied. One indication of that was that the C.F.R. Committee—an American committee—considered at present that the bouncing pin should be retained as the standard method of detection. The temperature plug method, however, required to be very fully explored, especially in its application to complete aero engines. The methods of knock testing which had been developed within the last two or three years should be regarded as preliminary only. A number of people were present whom he knew to be connected with this kind of work, and he hoped some of them would join in the discussion.

Mr. H. C. MANSELL (Bristol Aeroplane Co., Ltd.): The Bristol Company had long felt that tetraethyl lead was the only really practical anti-detonant which

would enable fuel for aircraft engines to be brought up to the necessary standard to maintain progress of the aero engine.

His company had carried out experimental work for a number of years and had met certain difficulties which gradually had been conquered, largely by the means outlined by Mr. Banks. Undoubtedly one of the chief points was the maintenance of a really gastight exhaust valve. With ordinary fuels, slight distortion or leakage might not lead to serious trouble, or affect the performance appreciably, but with tetraethyl lead, corrosion might start and burning rapidly take place. By change of the insert material, however, and by detailed attention to the valve itself, together with sodium cooling, full type tests have been carried out on D.T.D. 230 fuel with the full 4 c.cms. lead concentration. Substantial increase in power output together with gain in fuel economy have been obtained on the new series Pegasus and Mercury engines.

This was regarded only as the starting point, and progress, it was hoped, would be very rapid during the next few years, when mean pressures of 160 to 200 lb./sq. inch would come about, with cruising consumption of below .45 lb./b.h.p./hour.

Experience was now required in service, particularly on the corrosion of the exhaust ring; satisfactory running temperatures would have to be determined, and it would have to be seen whether magnesium parts, such as carburettor bodies and tanks were affected by the fuel. In this connection, the American experience led one to believe that the difficulties would be overcome, and D.T.D. 230 fuel with its lead content could be regarded as really a start towards the higher standard fuels which will rapidly be required and corresponding further increased power outputs will materialise.

Mr. Banks had raised the question of fuel matching, and Mr. Pye's remarks were very welcome in that connection. The speaker felt that an international agreement on knock rating would be most valuable at the present time as the octane value at present always had to be referred to the method of testing, and one was not free to compare performance or be assured exactly as to what grade of fuel had been used.

The CHAIRMAN: He should have mentioned in his previous remarks that the I.P.T. was working in the closest co-operation with the C.F.R. Committee in America, so that the international agreement which Mr. Mansell had referred to was well on the way to being achieved.

Mr. THORNYCROFT, A.F.R.Ae.S. (Messrs. Ricardo & Co.): He had not yet had an opportunity of reading the whole of the paper, and possibly somewhere in the text Mr. Banks had answered the question he desired to ask, namely, whether Mr. Banks in his experience had found any effect on the amount of carbon deposit due to large concentrations of lead—that is to say, whether two fuels, one with lead and the other without lead, but both of the same octane number, would probably show the same weight of carbon deposits and the same tendency or not to "ring gumming." Mr. Banks had referred to the effect of detonation in increasing the temperature of the cylinder and to the fact that the overheating due to detonation had been suspected as the cause of increased carbon deposits in the ring grooves leading to ring gumming or sticking of the rings in the piston grooves. On the subject of ring gumming certain experiments in which the speaker had been concerned were possibly of interest. The experiments were made to determine the effect of detonation on the rate of gumming of the piston rings when the temperature of the cylinder was maintained constant. Under these conditions it was found that quite a small degree of detonation greatly reduced the time of running before ring sticking occurred owing to the more rapid formation of carbon deposits in the grooves. The tests were carried out on a small single-cylinder air-cooled unit in which, by means of varying the cooling blast, a constant cylinder temperature of 270°C., measured by thermocouple near the top of the bore, was maintained. At this temperature in 10

hours of running, the side clearance in the top ring groove was reduced almost to zero by the carbon deposit when detonation was absent, that is when a fuel of high octane number was used. Starting again with a cleaned piston, but with the fuel changed for one giving only slight detonation, the cooling blast having been increased so as to maintain the same cylinder temperature as before, the top piston ring became stuck in its groove in five hours. The experiment had been repeated several times and always with substantially the same result. This apparently direct effect of detonation on the depositing of carbon in ring grooves was perhaps not generally known, although possibly it might have been inferred from the fact that the exhaust from a detonating engine was often observed to be black. These experiments had provided further evidence of the importance of suppressing all detonation.

Mr. A. C. LOVESEY (Messrs. Rolls-Royce): The paper supplied much useful information at the right time. Everybody appreciated the advantages of leaded fuel in permitting an increase in the power rating of engines and the author had certainly not attempted to conceal some of the troubles which arose with various parts of the engine when using lead. It was only by a full appreciation of these difficulties and realising all the troubles encountered that we were likely to be able to get over the difficulties. On behalf of his firm he had carried out rather extensive investigation on valve burning with leaded fuel, and it might be of some interest to compare notes with the author. Firstly, he fully supported the theory of the mechanism of failure advanced by the author, *i.e.*, one of the chief differences observed between the behaviour of valves which had operated with leaded fuel and those which had operated with ordinary straight fuel was that after a quite short period of running—three or four hours—a fairly hard scale formed on the valves which had been running with leaded fuel and this seemed to increase somewhat in thickness with the period of running. Micro-photographs which had been taken showed that this highly glazed scale had a thickness of about .002 inch although the section was rather thicker on the outer edge of the valve and tapered off towards the inner part of the valve. Valves which had operated, even for considerable periods, without lead did not exhibit this hard glaze and could be cleaned up to show the bare metal on the seating face.

The instances of lead attack that he had seen started in the form of V-shaped fissures from the outside of the valve, which gradually got deeper and deeper right across the face, and then there seemed to be a very rapid failure caused no doubt by the blow-pipe effect of the flame blowing through on explosion. It seemed, however, that it was necessary to accept the position that the valve must operate under these conditions of scale. He had also associated the failure of the valves with distortion, but it seemed that most of this distortion occurred at the valve seat inserts. During most of the investigation carried out, both in this country and America far more attention appeared to have been paid to the valve than the seat, but from the work he had done he had found that more progress was made by paying careful attention to the design and fitting of the valve seating insert.

At first sight it was rather difficult to associate the burning out trouble on lead with distortion because similar distortion should occur when running with unleaded fuel and the valves did not then give trouble with burning out, even when operating at the same power output. The explanation might be that when distortion took place in the presence of the scale caused by leaded fuels the unit loading went up on some portions of the scale which caused it to break down.

He did not agree with the author on the question of valve temperature, because some of the most satisfactory valves in his experience had been uncooled valves running at from 750 to 800°C. In the early stages it was thought that valve temperature was an important feature and he had gone to the extent of cooling valves with sodium to the maximum extent. The heads of the valves were fully cooled and the sodium came within one-tenth of the valve seating, but these valves gave trouble very much more quickly than uncooled valves.

As regards materials, he had not found very much difference in the range of materials tried which was from chrome steel to austenitic steel of the K.965 type. He had tried stelliting steel, but that had worse results than with ordinary valve steel. In the case of stelliting the scale caused by the leaded fuel did not adhere to the surface quite so well and the flaking off of the scale took place very much more quickly, resulting in blow past and quick failure. In that connection also mention might be made of the use of stellited tips of sparking plugs to prevent erosion or burning away, but so far that had not been very successful.

Some of the American firms had obtained improved results by increasing the size of their exhaust valves, and while it was considered the improvement was due to lowering the exhaust gas velocity it was probably more likely to be due to the introduction of more uniform bedding under working conditions; this prevented high pressure on the various parts of the scale and consequently avoided the breaking down of the surface.

Another point of interest was that in trying to bring up the lead effect rather quickly, tests were run on valves raised off their seats slightly, to imitate the distortion, but in that case no lead attack occurred. That was possibly due to the absence of the hammering to form the scale and there was not the pressure to break it down.

Mr. F. A. Foord, A.F.R.Ae.S. (Air Ministry): The author was in an unique position inasmuch as he had the entrée to the works of both British and American aircraft manufacturers and therefore was able to speak with authority regarding their troubles and successes. The people concerned with the future of aero engine fuels attached tremendous importance to the use of tetraethyl lead; but as the experience already obtained merely had the effect of increasing their thirst for further knowledge, there were one or two points he would like to put to the author. One was that with the higher concentrations of lead in the fuel (4 c.c.s and above) was the author satisfied that the conditions of storage which he advocated were adequate to prevent corrosion, because after all said and done corrosion in storage was a most important thing for the Air Force and there had been rumours of trouble in that respect? In addition, what was the position with magnesium and leaded fuels in this respect? Secondly, was the author able to say whether the conditions of the type test on the bench were comparable with those in the air? From the point of view of erosion of the exhaust valves a great deal of bench testing work had been carried out with successful results; but unfortunately there had not been the same considerable experience in the air and, personally, he had doubts as to whether the conditions were actually comparable, more particularly with high concentrations of T.E.L. Again, did the author think that 100 hours on the test bench was sufficient to show up the difference between a small quantity of lead and a large quantity of lead in the fuel? He was willing to agree that with the 100 hours' test the differences were small, but engines ran for longer periods than that in the air and overhaul periods were from 400 to 500 hours.

Finally, in the search for anti-knock fuels, which was going on at a tremendous pace—and must of necessity go on if we were to maintain our place in the air—octane numbers of 100 and even more were being thought of; but it was quite a marked feature of the use of tetraethyl lead that the effects fell off on a very flat curve when one got up to 7 c.c.s per gallon. The author had advocated that when these ultra high anti-knock fuels were required a combination of lead and aromatics should be used, but it was probable that in times of emergency the aromatics would not be available. It seemed, therefore, a question of how we should obtain these high anti-knock values in times of emergency, particularly as there seems to be some doubt on the question of using T.E.L. effectively when blended with cracked spirits, hydrogenated fuels or coal spirits of relatively high octane numbers.

Mr. H. B. TAYLOR, A.F.R.Ae.S.: While he agreed almost entirely with everything in the paper, he could not help feeling that the author had skated rather lightly over corrosion attack. From the earliest days of the use of lead in this country corrosion attack had been a very difficult problem, particularly in storage, although no doubt the improvement in materials had considerably reduced these effects. He was not referring to keeping engines in store but to keeping engines in the machines for a week or so, when it was not possible to pour pints of oil into the cylinders to prevent corrosion, especially when some of the cylinders were upside down. There were risks of corrosion attack when engines were standing in the open in bad weather perhaps for weeks, and the author had skated rather lightly over that, which seemed to be a serious trouble—at any rate it was in the early days.

Commenting on the sentence in the paper that people had fallen over one another to show that leaded fuel could not be used satisfactorily, Mr. Taylor said that having been associated as he had been with the use of leaded fuel from the beginning, he had naturally encountered difficulties and pointed them out, but the author should not construe that into a justification for saying that people fell over one another to prove that leaded fuel could not be used. As to poisoning, there was one man who, in spite of warnings as to the methods of handling leaded fuel, used to syphon it out with his mouth! From this point of view it was very comforting to hear the author say that leaded fuel is now innocuous so that possibly the danger from poisoning was not the reason why this particular man was no longer with us! One of the biggest setbacks to the use of leaded fuel was the unfortunate case in America when a number of people were killed, due to a breakdown in the plant; that, of course, was not due to the scientist, but he was happy to know that all that had now been overcome and that everything was perfectly safe to handle in use.

The use of steel valve seats seemed very largely to be the solution of the problem of the use of leaded fuel. He had known of cases where steel seats had been quite satisfactory with leaded fuel, but not with a straight fuel, and that was in all probability due to the layer formed by the lead, which seemed to be a useful thing to have. Up to date, using steel, he had not found any real cases of valve burning and from his experience it rather seemed that the air-cooled engine was very much better off when using leaded fuel than the water-cooled engine. He had certain reasons for saying this and one was the slightly higher operating temperature which disposes of the products more efficiently than does the water-cooled engine.

Mr. R. B. BUTTERFIELD (Messrs. Pratt and Whitney): He expressed the appreciation of himself and Mr. Hoffman at having had the opportunity of listening to the discussion. As the author was very much more closely in touch with fuel activities in America than himself, it was not possible to say much on the paper. Many of the points brought out, particularly, as to the effect of benzol as compared with lead, and the different amounts of lead or combinations of the two, had been borne out by his own experience.

Major G. P. BULMAN, F.R.Ae.S. (Air Ministry): While he had declined the Chairman's invitation to open the discussion because he had nothing of technical interest to offer, it would be churlish of him to neglect this opportunity of expressing to the author, on behalf of his colleagues and himself at the Air Ministry and, indeed, the aero engine industry generally, for whom, in this instance, he might claim to speak, their very deep sense of gratitude for the extraordinary help the author had given in connection with their united attack on problems related to leaded fuels which had been going on for the past two years, to secure to the Royal Air Force the benefits offered by such fuels. Mr. Foord had stated that the author had the entrée to all the English engine firms, but it should be said that that entrée had been gained by the author on the strength of his own personality, the complete absence of mystery, hot air, and

apparent axe grinding which distinguished him, and his wealth of commonsense. Mr. Banks was always ready to face up to bad results as well as good, regardless of whether his firm's interests were apparently served or not; he did not try to explain away difficulties, but was concerned always and only with establishing the true facts of the case and to ensure sound and steady progress.

Mr. P. W. S. BULMAN, F.R.Ae.S. (Hawker Aircraft, Limited): He would like to take the opportunity of corroborating the statement of his namesake with regard to the very great help the author had been to everybody who had had occasion to use T.E.L. As representing the aircraft side of the industry as distinct from the aero engine side, he wished to say how much the author had assisted users of this material. He had not had sufficient experience of aero engines when running on T.E.L. to be able to give an opinion on the corrosion problem, but had in use an antique motor car of Transatlantic origin which had covered 80,000 miles in five years, mostly on Ethyl fuel, and which had had no attention other than twice being decarbonised. He had to admit that the car engine did not run for such long periods at high output as the aero engine, but suggested that the greater number of cold starts would be more likely to lead to corrosion.

Having had the privilege of flying aircraft with supercharged engines using fuel with 3 or 4 c.c.s of lead per gallon, he could testify to the very great value of the extra power which was available. Civil aircraft could make use of this extra power for emergency take-offs from small or high altitude aerodromes by carrying lead fuel in the reserve tank and military aircraft could operate their fully supercharged engines at full throttle at low altitudes for short periods in time of war.

The CHAIRMAN: Before calling upon the author to reply, he wished to associate himself with all that Major Bulman had said about the great assistance that had been rendered by the author in regard to the use of leaded fuels. Speaking with regard to the paper, the Chairman said there was one point he would like the author to expand a little more, possibly in his written reply to the discussion. It was stated that detonation tests on single aero engine cylinders were difficult to compare with those done on complete engines; and he thought that that point should be expanded a little further because, as it stood, the statement was a little difficult to understand. Detonation was a thing which occurred in a particular cylinder by reason of the conditions in that cylinder, and independently of the remainder of the cylinders in an engine. If a single cylinder was arranged to work under conditions properly representative of the worst cylinder in a multi-cylinder engine, then why should not the knock-rating arrived at from tests on that single cylinder co-relate with the knock-rating appropriate to the multi-cylinder engine?

REPLY TO DISCUSSION

Mr. Pye.—Referring to the Chairman's introduction and subsequent remarks the author wished to thank Mr. Pye for his very kind references to himself and to say how much he appreciated them, particularly because they came from one who is an acknowledged authority on matters pertaining to internal combustion engine research and development.

The author quite appreciated Mr. Pye's remarks regarding the conduct of the knock-testing work and correlation which was done under the auspices of the sub-committee of the Institution of Petroleum Technologists and which he, the author, criticised somewhat in his paper. He felt, however, that the conditions evolved for the C.F.R. knock-testing unit, as a result of this work, had been formulated a little hurriedly, having regard to the limited scope of the original investigation and particularly because they had now been accepted by the Air Ministry in order to test fuels under the new D.T.D. 224 and 230 specifications. The latter fuel was of rather a different nature to any of those tested

in the I.P.T. investigation, in that its octane value was considerably higher, *i.e.*, 87, and tetraethyl lead could and would be used to achieve this knock rating in the final fuel.

He was pleased to learn from Mr. Pye that further work was being done in this direction and that leaded fuels of high octane value, with varying concentrations of lead up to, perhaps, 7 c.c.s per gallon, would be investigated. Also, that tests with some of the fuels would be done on complete engines. With regard to Mr. Pye's request for him to expand further on his criticisms of single-cylinder conditions compared with those on complete engines, the author stated that he did not intend to convey the impression that he was condemning the work already done by the I.P.T. sub-committee, but he wished to put forward another point of view in order that any weak points found in this investigation could be strengthened further or eliminated in subsequent investigations. For instance, work on complete engines might have been done in order to check the results obtained on the single-cylinder units. One still feels that it is very difficult to simulate single-cylinder conditions with those on complete engines, particularly of the air-cooled variety. There is probably less chance of local " hot spotting " with a single-cylinder job, where there is comparatively little interference to a direct draught of air, whatever the speed, than with a complete engine where, probably, quite an appreciable amount of eddying takes place.

The high powered air-cooled radial engine was a good subject for fuel investigation, and although the distribution was generally quite satisfactory and could, perhaps, be fairly accurately imitated on a single-cylinder unit, there were other points such as radiation and conduction of heat which might affect piston temperatures, etc. The crankcase design of a radial, as opposed to that of a single-cylinder job, because of the former's small volume in relation to cylinder capacity, must have some influence so far as heating effects were concerned. From the author's point of view, it was not possible to come to any definite conclusion until some work on complete engines had been done.

The " temperature plug," as a means of ascertaining the behaviour of fuels, should be thoroughly tried out and the author considered that it would probably be largely used when investigating fuels of different basic characteristics, although he thought that the bouncing pin method would still be employed for some time to come for routine knock testing, so long as fuels were tested under conditions, in the knock-testing engine, which took into consideration their behaviour, so far as temperature effect was concerned, on complete engines. The tests now being done at Farnborough with the temperature plug, together with the further correlation work mentioned by Mr. Pye should give a good idea of what was needed in order to provide matched fuels which allow satisfactory engine performance.

Mr. Mansell.—In reply to Mr. Mansell, the author said that he was fully in agreement with the need for an international method of matching fuels. At the present time, in some countries, things were perfectly hopeless and one had often met cases where an engine was giving trouble on a fuel of a certain quoted octane value, say 80, when it had previously been developed on one of 76, and had performed very well indeed on the latter. Upon investigation one would find that, either the fuel had been tested by a laboratory with little or no experience of knock-testing technique or, that the value had been ascertained under widely different conditions to those under which the original fuel was tested.

Actually, things were improving and the C.F.R. fuel knock-testing engine was now accepted in Great Britain and the U.S.A. as the standard equipment for such work. This engine was not yet accepted internationally, but all the major and representative oil companies, with world-wide distribution, had agreed to standardise the C.F.R. unit, and it only remained for the engine builders to ask for, and obtain fuel, the octane value of which had been ascertained on this

engine under a certain set of conditions, the " motor method," for instance, and similar fuel could be supplied internationally, from the branches of the companies concerned.

The author wished to congratulated Mr. Fedden and his staff on the very successful type test runs made by the " Pegasus III " and " Mercury VI " engines on fuel to A.M. D.T.D. 230 specification containing 4 c.c.s of lead per gallon. He, the author, was privileged to attend the examination of both these engines and could testify that they stripped in excellent condition. This was the result of a great deal of hard work and sound technical development.

The author did not think that any great troubles would be experienced with such fittings as exhaust rings, provided that due attention was paid to materials and running temperatures, etc. His experience of magnesium alloys (although expressed in his paper, he would like to repeat it here) was that until some suitable treatment had been found for these alloys, they should not be employed for fuel tanks, whatever the fuel used, leaded or unleaded. He did not think, however, that any more trouble would be experienced with a leaded fuel, when these alloys were used for carburettor bodies, supercharger casings, induction systems, etc., than that which might be found with an unleaded fuel.

Mr. Thornycroft.—Replying to Mr. Thornycroft, the author understood that the principal point raised by Mr. Thornycroft was a query as to the effect of leaded and unleaded fuels on the formation of carbon. Although he did not know of any specific work which had been done in this direction, the general view held was that somewhat less carbon was formed over a given period with a leaded fuel than with one which did not contain lead. An initial deposit of small thickness, consisting generally of lead bromide, lead sulphate and some carbon, etc., seemed to form fairly quickly in the early stages of running, but did not increase substantially in amount during prolonged operation.

So far we, in this country, had not experienced ring sticking trouble with leaded fuels and it was not, in the author's opinion, a trouble which need be anticipated. Further, in tests done on the Continent, where castor oil was used in many cases, no acceleration of the normal ring sticking troubles usually associated with this lubricant, was observed. In one particular case, the firm concerned stated, quite definitely, that their rings were in better condition after running on a leaded fuel and using castor oil, but one accepted this with reserve because no check tests on this particular point had been done.

The results of the ring sticking tests mentioned by Mr. Thornycroft were most interesting and valuable and he (the author), personally, had had parallel cases, although the tests in those cases had not been so detailed or comprehensive as those done by Mr. Thornycroft. A number of ring sticking cases was found, accidentally, when examining engines after trouble had been experienced due to detonation and overheating. The rings having stuck well before the period they were known to have run normally without trouble. Perhaps this might be, to some extent, due to the presence of free carbon which is usually noticeable when detonation is present.

Mr. Lovesey.—In replying to Mr. Lovesey, the author was very pleased to hear that Mr. Lovesey confirmed his own views of the particular mechanism which led up to valve trouble, in cases where leaded fuel was used. A great deal of what Mr. Lovesey said could be explained; firstly, he (Mr. Lovesey) stated that he had not found that very hot valves gave more trouble than ones which ran considerably cooler, and in fact, some fully cooled sodium filled ones had given trouble more quickly than uncooled valves under similar conditions. This was probably due to the type of engine concerned, which was a V-type " in line " job having 12 cylinders with four valves per cylinder. The valves were, therefore, relatively small in size and, consequently, had some degree of inherent stiffness about the rim and head.

Assuming that distortion of the cylinder head and valve inserts was present, some part of the valve would be away from its seating and blow past of the gases would occur. Now, if the valve head was efficiently cooled and ran at a comparatively low temperature, say, 650°C., it would retain its stiffness and refuse to reseat itself or conform to the distorted insert seating. No amount of cooling would prevent the material of the valve seat from burning when subjected to the " blow pipe " effect of hot gases passing through a very small passage between the valve seat and insert. It was conceivable that an uncooled valve with a hot head might tend to reseat itself more easily under these conditions, because of some degree of plasticity of its head, due to high temperature.

Another theory suggested by the author was that lead bromide, because of its high boiling point, about 920°C., would not tend to condense so easily on the surfaces of the valve head, if the latter was kept at high temperature, therefore the bromide would be more easily evacuated from the cylinder and would be less liable to attack the valve material. He, himself, however, did not have much faith in such a theory, because the valve temperature was usually lower than that of the boiling point of lead bromide and, under running conditions, the bromide was probably well mixed with the other products of combustion which were at high temperature, above that of the valve, consequently the bromide probably remained in gaseous form until it reached the other side of the exhaust valve. Some, naturally, condensed on the piston and cooler parts of the combustion chamber. From the author's experience, too, the rate of attack of the valve material by lead bromide or the products of its decomposition, rose very sharply with increase in temperature.

He considered that it would be a retrograde step to develop hot running valves because of this particular case and in any event the weight of evidence in this country, the States and in Europe was all the other way. Such a development would definitely limit engine performance and there would probably be a rapid build up of scale on the valve head, eventually leading to pre-ignition troubles.

The author was aware, however, that Mr. Lovesey was in general agreement with him in this matter and the distortion problem had been attacked with success and this, together with a partially cooled valve, had overcome the trouble. Undoubtedly, completely cooled valves would have to be used if and when the power outputs of engines were increased further.

Mr. Lovesey mentioned that while a valve would give trouble with a leaded fuel when cylinder head distortion was present, it was often satisfactory despite this distortion, with an unleaded fuel. This might be due, as he states, to increased loading causing local breakdown of any scale which may have formed or, as the author stated in the paper, which was practically the same thing, the uneven formation of the characteristic scale.

The author thought, however, that the basic difference between the effects of leakage past the seat, when using leaded and unleaded fuels, was that, in the former case, the presence of lead bromide greatly accelerated the trouble by causing " hot " corrosion attack of the valve material at the point of blow past but that it would only be a matter of time for an unleaded fuel to cause trouble if gas leakage was present. Another point brought up by Mr. Lovesey was that in attempting to accelerate the lead effect, he ran tests with valves slightly raised off their seats, but the author could not agree that this was the same thing as distortion, where only a part of the valve was away from its seat. Although the whole valve probably ran at a higher average temperature in the former case, it was probably not subjected to such an intense local temperature as would be the case under the latter condition.

He could not agree with Mr. Lovesey regarding the use of " stellited " valves. True, Mr. Lovesey's firm had not had 100 per cent. success, but it must be remembered that the application of " stellite " required a considerable amount

of practice and technique and also, although " stellite " undoubtedly had a very high resistance to " hot " and " cold " corrosion attack by lead bromide or the products of its decomposition, practically no material could stand up to the blasting effect of gas leakage at high temperature and pressure. Mr. Lovesey tried stellited valves at a time when he was not by any means " out of the wood " as regards valve trouble, and considering all the difficulties involved, the author thought that these valves were very creditable jobs indeed. One of the desirable features of " stellite " was that it resisted scale formation so well.

The use of " stellite " had definitely got many engines out of trouble. Some firms in America, who manufactured 'bus engines, suffered severe valve burning troubles regardless of the fuel used (leaded or unleaded), but eliminated these troubles by stelliting the valves.

In this country, during the early attempts, two years ago, to pass type test on leaded fuel, very successful results were obtained, in two different engines by stelliting the valve only, even although it was the insert which was the primary cause of the trouble experienced with the original and unstellited valve. The actual type test was not passed with a stellited valve because it was eventually found that the insert was the chief cause of the trouble, but from the results of considerable test running it was practically proved that these particular engines could have passed the type test satisfactorily with no alteration other than the use of stellited valves. In fact, they ran an equivalent number of hours to the type test under appropriate conditions.

Mr. Lovesey's firm had done a tremendous amount of work on the development of engines to use leaded fuel and they were to be congratulated on the successful results obtained and for the valuable data which had been compiled.

Mr. Foord.—In reply to Mr. Foord, the author said that Mr. Foord had raised some very interesting points. Firstly, with regard to the higher concentrations of lead in the fuel and their effect upon the conditions of storage, he (the author) was not satisfied with the conditions he had mentioned in the paper, but felt that the question of storage had been somewhat overstressed and was always made out to be a mountain whereas a molehill was, in his opinion, the more correct perspective to take. He did not mean that it was not an important point to consider, but he thought that storage troubles had always been secondary to those experienced under running conditions.

He had not gone to greater lengths with regard to " cold " corrosion and storage, because he felt, also, that there was no reliable data available and he did not think that these effects would be so pronounced with the valve materials and improved lubrication we had to-day. It was a peculiar fact that ever since the early days of lead, so far as aviation fuels were concerned, " cold " corrosion was always looked upon as the chief " bogey," whereas in the light of experience, exhaust valve failure would really seem to be the principal trouble.

The probable explanation of this was that the Americans, when they started to use leaded fuel, were using exhaust valves made from cobalt-chrome and other steels which were not very high grade as regards strength at elevated temperatures and, also, resistance to corrosion. Cobalt-chrome was particularly bad so far as corrosion was concerned. The American engines were mostly of the air-cooled type which had partially (very partially) lubricated valve gears, consequently the valve stems were usually dry and if the engine was laid up for short periods without attention, the valves corroded so badly that they stuck in their guides and often had to be driven out.

The American manufacturers had little experience of the austenitic steels in those days, not so much as we had over here, in fact. Therefore, it would be readily understood that corrosion troubles were magnified and exhaust valve troubles, which were probably quite frequent in those days on ordinary fuels, did

not, under the then relatively low duty flight conditions, show up much worse with leaded fuel and were accordingly relegated to the background.

*The author hoped to be in possession of a report dealing with the question of " cold " corrosion and if it came to hand before his paper was published in the Society's Journal, he would include it in the paper. From what he had already heard, this report bore out his contentions that, with austenitic valve steels and adequate lubrication, no great trouble was now experienced, although, of course, suitable precautions should still be taken.

With regard to magnesium alloys, he would refer Mr. Foord to his paper and also his reply to Mr. Mansell. He could not at the moment go further because there was no definite information on this point beyond the experience they had had with fuel tanks.

He was definitely of the opinion, so far as this country was concerned, that the type test conditions were much more severe than flight conditions, from the point of view of exhaust valve life. He did not think that test bed and flight conditions were comparable in this country, although they were, perhaps, more comparable in America where engines were now being asked to develop a " cruising " power of about 18 b.h.p. per litre for the high speed civil air line machines.

We had not, so far, been able to show up any appreciable difference between small and large concentrations of lead, in the tests done in this country over 100 hours' duration. Once the valve gear was right for a reasonably high concentration, say, 4 c.c.s, the author did not think that an increased concentration would matter very much, particularly under flight conditions. Perhaps the sparking plugs might feel the difference, but there was no evidence of this so far.

One of the American engine manufacturers had informed the author's company that they could detect sharp differences between 3 c.c.s and 6 c.c.s of lead in about 26 hours' running on the test bed.

The author thought that fuels should stand at about 87 or 90 octane under conditions of test similar to those used at present, because he was certain that the engine manufacturers would be able to do quite a lot in the next two or three years by careful development. In fact, so far, we had not had any really practical experience of fuels higher than 77 octane. It might be that the *numerical* octane value of the fuel would remain around, say, 90, but the conditions of test would change at reasonable intervals to keep pace with engine development.

Regarding the future supplies of suitable basic fuels in order to reach still higher anti-knock values with lead, the author thought that synthetic aromatics could be produced satisfactorily. The addition of lead to spirits containing " cracked " stock, or to hydrogenated fuels and also to " straight run " spirits of high initial anti-knock value was in every way satisfactory.

Mr. Taylor.—Replying to Mr. Taylor, the author stated that he had purposely dealt with " cold " corrosion attack rather broadly for the reasons stated in his reply to Mr. Foord. He did not agree with Mr. Taylor that it was neces sarily a difficult problem to tackle. The tests done at Farnborough some years ago on various engines, according to the reports, showed that the corrosion attack was relatively slight and the only parts that really suffered in this respect were some cobalt-chrome exhaust valves. The attack on these was admittedly serious, but they could have been changed very easily for ones of K.E. 965 material. Cylinder bore rusting was not apparently very pronounced or noticeable.

In the light of recent experience the author did not think that it would be really necessary to pour oil into the cylinders of engines which were to be left

* The report referred to had now come to hand and is published under Appendix V at the end of the paper.

standing for a week or so. If it was found to be necessary then he did not think that there would be much difficulty in introducing some suitable fluid or oil into the engine cylinders via the induction pipe, as suggested in the paper. He thought that any engine, whatever the fuel used, would suffer rather badly if left standing in the open for weeks in bad weather.

The author considers that he was substantially correct when he stated that many people tried to condemn the use of tetraethyl lead in fuels, for various reasons of their own, and there is plenty of evidence in support of this. He did not, however, include Mr. Taylor as an offender in this respect, although he thought that Mr. Taylor would admit that the development of engines to use leaded fuels had not been pressed very hard after the first troubles manifested themselves, and it was not until about two years ago that the problem was re-attacked. The fact that corrosion troubles were looked for in the early days and subsequent running disclosed exhaust valve failures, showed how little every-one knew about lead at the time.

Since presenting his paper the author has confirmed that the engines tested at Farnborough ran on castor oil and were stored with castor oil still in them, although, he believes, in some cases, that mineral oil was put into the cylinders *without* removing the castor.

With regard to the toxic effect of lead; this was as stated in the paper and no trouble need be anticipated when lead is blended in a fuel. It may be mentioned here that leaded fuels have been sold in the U.S.A. and Canada for eight or ten years and in Great Britain for six years, continuously, and in large quantities, without one case of poisoning. Ten years of medical observation have confirmed that all fears regarding the handling and use of leaded fuels are groundless.

The author agreed that a man who is fool enough to syphon out fuel by his mouth, whatever the nature of the fuel, should not hold a responsible position.

He did not agree that the biggest setback to the use of leaded fuel was the accident in America. It certainly received publicity in the Press in the States at the time, but this soon died down when it was realised that the accident was due to an explosion of an autoclave of the experimental plant in which the manufacture of tetraethyl lead on a commercial basis was being investigated. The men were killed primarily because of the explosion and their deaths were not in any way due to the handling of leaded fuel. Mr. Taylor might have spared us this old bogey.

The author was glad to have Mr. Taylor's views on the valve question and he thought that the trouble experienced with a " straight " fuel and steel inserts was probably due to the " picking up " tendencies of two steels in contact with one another, particularly if they were of the high nickel-chrome variety. He thought, however, that this trouble could be overcome fairly easily and it was just a matter of finding, perhaps, a suitable seat width and loading and, possibly, altering the shape of the valve head. He had seen other engines which had run quite satisfactorily on an unleaded fuel with a similar combination of valve and insert materials.

Mr. Butterfield.—In answer to Mr. Butterfield, the author was very pleased to have confirmation from his friend Mr. Butterfield and also Mr. Hofman, of the relative effects of benzol and lead. The firm which Mr. Butterfield represented had done a tremendous amount of sound experimental work on fuels, a lot of it on complete engines.

Major Bulman.—In reply to Major Bulman, the author thanked Major Bulman sincerely for his very kind remarks about himself. He (the author) wished to say how much he appreciated the courtesy and kindness which was always extended to him when he had occasion to visit officials of the Air Ministry.

Mr. P. W. S. Bulman.—Replying to Mr. P. W. S. Bulman, the author thanked him for his very kind remarks and was pleased to note that Mr. Bulman was substantially in agreement with him regarding the uses of leaded fuel in aircraft operation. This was most interesting, coming from a test pilot of such distinction, and although Mr. Bulman never admitted it, the author considered that his (Mr. Bulman's) knowledge of aviation engines was considerable and this also lent further weight to the statements he made.

The author had had the privilege and pleasure of flying with Mr. Bulman in machines fitted with fully supercharged engines, using leaded fuel of high anti-knock value, and could confirm, if confirmation was needed, that the performance was phenomenal. A study of the curves, shown in Fig. 1 of the paper, would give a good idea of the improvement in performance obtained with such a fuel in a high performance machine.

Mr. Bulman and his staff had always been of great assistance to the author when pursuing his investigations or seeking information on aviation matters.

ABSTRACTS OF PATENT SPECIFICATIONS

(*Specially abstracted for the Journal by W. O. Manning, F.R.Ae.S.*)

Regular abstracts of Patent Specifications received by the Society are published in the Journal. It should be noted that these abstracts are specially compiled by Mr. W. O. Manning, F.R.Ae.S., for the Journal and are only of those actually received and subsequently bound in volume form for reference in the library. These volumes extend from the earliest aeronautical patents to date, and form a unique collection of the efforts which have been made to conquer the air.

The Council accept no responsibility whatever for the accuracy of the abstracts and in any case of doubt the full patent can be consulted when necessary in the library of the Society.

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Aerofoils

404,270. *Improvements in Aircraft.* Zap Development Corporation, 230, Park Avenue, City and State of New York, U.S.A. Convention date (U.S.A.), April 3rd, 1931.

This specification refers to means for increasing the lift of aeroplane wings by placing a drag producing element at the rear of and on the underside of the wing. Results of tests are given and the best position for the flap is stated. Various forms of the flap are described, including shapes concave or convex in the direction of flight and an arrangement is described for combining these flaps with ailerons.

404,149. *Improvements in or Relating to Aerofoil Surfaces.* The Fairey Aviation Co., Ltd., Cranford Lane, Hayes, Middlesex, and Huxley, M. F., 136a, Northfield Avenue, West Ealing, London, W.13. Dated February 2nd, 1933. No. 3,223.

This specification refers to slotted aeroplane wings and has for its object the prevention of the risk of the slat being jammed, due to unequal pressure distribution. The slat is carried by telescopic members which are mounted on the aerofoil so that the angles between their axes and perpendiculars to the longitudinal axis of the slot are greater than the angle of repose. The movement of the slat may be either rectilinear or curvilinear, and the telescopic member may be provided with rollers to reduce friction. An application of the arrangement is described for use with a tapered wing where it is possible to arrange for the movement of the slot away from the wing to vary with the chord.

Aeroplanes—Construction

403,911. *Improvements in Landing Trains for Aeroplanes.* Societe Francaise de Matèriel d'Aviation, 58, Rue Fénelon Montrouge (Seine), France. Convention date (France), July 13th, 1933.

This is an arrangement of a chassis of the axle-less type in which the axle of each wheel is rigidly attached to a member projecting obliquely upwards, this member sliding in an external tube containing shock-absorbing mechanism. In the arrangement described the internal tube is not allowed to touch the external tube, but is guided at the lower end by rollers and at the upper end by a piston attached to it by means of a ball joint, the piston being in its turn attached to the damping mechanism. The object of the arrangement being to prevent binding of the mechanism in the event of any member deflecting under load. The guiding rollers act on projections on the internal tube in such a way as to transmit any torsional loads.

401,598. *Improvements in or Relating to Constructional Parts for Aircraft and Watercraft comprising Strengthened Metal Sheet.* Societa Italiana Ernesto Breda per Costruzioni Meccaniche, 9, Via Bordoni, Milan, Italy. Convention date (Italy), June 18th, 1932.

It is proposed to strengthen metal sheet by forming in it elongated raised parts or bosses produced by local stamping, the raised parts being arranged in parallel rows. These bosses may be staggered in respect to each other or they may be aligned in the direction of the minor axes of the bosses. It is pointed out that such a sheet is substantially rigid in one direction, but is flexible in a direction at right angles to this direction. If it is desired to stiffen the sheet in all directions this may be done by attaching a separate bossed sheet or sheets so that the angles of the major axes on the bosses of the latter sheet or sheets cross the same axes of the bosses on the first sheet. The sheets are connected together by riveting, bolting, or welding.

406,138. *Improvements in and Relating to Cockpit Windscreens Particularly for Aircraft.* Petters, Ltd., and Davenport, A., both of Westland Works, Yeovil, Somerset. Dated March 27th, 1933. No. 9,152.

This specification describes a windscreen for the rear seat of a two-seated aeroplane in which the two seats are disposed in line. It is proposed to curve this windscreen into the form of a portion of a cone or of a cylinder, and it is stated that this arrangement maintains a comparatively smooth flow of the air deflected by the front windscreen and so conduces to the comfort of the pilot and the occupant of the rear cockpit. Means are described so that the windscreen may be disposed eccentrically to the machine so as to allow for the twist of the slipstream, and an arrangement is shown by means of which the windscreen may be removed in flight, if desired.

404,944. *Improvements in or Relating to Light Metal Structures for Aeroplane Wings or the Like.* The Bristol Aeroplane Co., Ltd., and Pollard, H. J., both of Filton House, Bristol. Dated July 23rd, 1932. No. 20,798.

This specification describes a method of constructing metal wings for aircraft in which the spars consist of a web formed of a flat strip of metal and the booms or flanges consist of corrugated and curved plates curving upwards, adapted to be closed by a cover plate. The ribs are shown as made in three parts which consist of channel-shaped stringers connected by zigzag bracing. These rib portions are placed in position with the spars and are then riveted to extensions of the spar complete. In addition, gusset plates riveted both to the spar webs and the rib stringers may be provided if required for strength. The

rib stringers may be riveted to the spar booms and the various metal parts of the construction may be corrugated.

404,963. *Improvements in and Connected with the Construction and Arrangement of Aeroplane Wings.* Marten, J., Marten's Aircraft Works, Higher Benham, Buckinghamshire. Dated July 20th, 1932. No. 20,520.

This specification describes a single spar construction for aeroplane wings. The spar proposed is triangular and generally not unlike the triangular girder used in airships, but it is constructed entirely of steel tube, the tubular longitudinal members being connected by a tubular bracing. The connection between these members is made by introducing into the longitudinal tubes a sleeve carrying internal nuts, brazed or otherwise attached to it, which take bolts or studs introduced through holes in the longitudinal members. The bracing tubes have their ends flattened and drilled for attachment by these bolts. Means for folding the wing are described and the spars may be either connected directly to the fuselage or the fuselage may carry a built-in stub spar to which the outer wing spars may be attached.

405,073. *Improvements in and Relating to Fluid-Pressure Brake Systems.* Avery, W. L., The Blue House, Thorley, Bishop's Stortford, Herts. Dated September 30th, 1932. No. 27,243.

This specification describes a system of fluid operated brakes for aircraft where it is arranged to isolate the brakes from the pump by means of valves after the pressure has been applied so as to prevent leakage, and at the same time permit additional pressure to be given. The pressure is applied directly by a hand-operated pump, the lever of which has a trigger which controls the valves, so arranged that when the lever and trigger are grasped the valves are opened. The valves are automatically closed immediately the lever is released. The additional pressure is applied to each brake by a separate pump fitted in the appropriate pipes. A modification of the arrangement suitable for automobiles is described.

405,132. *Improvements in or Relating to the Chassis or Undercarriages of Aircraft.* The Fairey Aviation Co., Ltd., Cranford Lane, Hayes, Middlesex, and Lobelle, M. J. O., Ludlow, Langley Road, Langley, Bucks. Dated March 22nd, 1933.

This specification relates to a method of constructing the chassis of a twin-float seaplane so that the movement of each float is independent of each other with a view to facilitating landing and taking off. The chassis described is, generally, of usual form, but the front transverse member of the chassis is arranged to be flexible while the rear transverse member is rigid. The floats are mounted to the chassis by means of shock absorbers fitted in the floats. The various joints in the chassis which are concerned with the separate movement of the floats are fitted with wires so as to permit the necessary flexibility. With this arrangement the floats are largely independent of each other with respect to their movement forwards, sideways and upwards.

Aeroplanes—General

404,166. *Improvements in and Relating to Flying Machines.* F. G. Y. Herrera, 12, Calle de Peligros, Madrid, Spain. Convention date (Spain), March 14th, 1932.

A form of flying machine, roughly on aeroplane lines, is described, in which compressed air is conducted to the leading edges of the wings and discharged as a stream passing tangentially over their upper surfaces, the compressed air being produced by an engine mounted in a central nacelle or fuselage. The size

and angle of the slot from which the compressed air issues over the wings can be varied, and it is proposed to use pressures varying from one-twentieth to one-fifth of an atmosphere. A foldable landing chassis is proposed which automatically projects itself at low flying speeds and automatically folds when the speed is high. It is locked in the landing position until the pilot presses a pedal.

403,613. *Improvements in Multi-Engine Aeroplanes.* Letov, V. T. na T., Praha-Letnany, Czecho-Slovakia. Dated March 22nd, 1932. No. 8,536. Complete not accepted.

It is proposed to compensate for unbalanced propelling forces, such as might occur on multi-engined aircraft with one engine stopped, by providing additional balancing planes which may be mounted on the ends of the wings, the ends of the tail plane, or the end of the fuselage. These balancing planes are rotatable about their vertical axes and it is preferred to place them as far as possible from the axis of the propeller pull.

400,735. *Improvements in or Relating to Aircraft.* Bolas, H., and Goodman Crouch, R. J., both of P.O. Box 375, Pawtucket, Rhode Island, U.S.A. Convention date (U.S.A.), December 31st, 1931.

This specification describes a means by which it is stated that heavier-than-air aircraft can be enabled to hover and to ascend and descend vertically while retaining the usual load carrying and top speed characteristics of aircraft already in use. It is proposed to do this by arranging that the propeller slipstream acts over substantially the whole of the main supporting surfaces so as to produce lift; the arrangement described also enables the controlling surfaces to be always in the region affected by the slipstream. Two general types are described, one in which the entire fuselage is tilted relative to the ground and the other in which the planes and outriggers carrying the control surfaces can be moved independently of the body so that the latter may be always approximately horizontal. The drawings show aircraft with main planes tilted at angles of incidence of over 45° to the horizontal position in the wash of inclined propellers. Claims are also made for means of tilting the engines of such aircraft, for the use of variable pitch propellers in connection with them, etc.

Airscrews

401,425. *Improvements in or Relating to Screw Propellers and Screw Fans.* Richard de Villamil, Lieut.-Col., 18, Priory Road, Kilburn, London, N.W.6. Date, July 7th, 1932. No. 19,228.

It is proposed to place a deflector in front of a screw propeller or fan instead of placing the propeller inside the deflector as is usually proposed. The deflector suggested consists of an annular ring and is shown in the drawings as having a diameter somewhat greater than the propeller. The section of the ring may be curved in the form of a cycloid or paraboloid, etc., and is arranged with its concave side outwards.

405,469. *Auxiliary Tube for Air and Water or Similar Screw Propellers.* Klutschareff, S., No. 2 Karadjordjeva ul 2 Pancevo, Jugo-Slavia. Convention date (Jugo-Slavia), February 27th, 1932.

It is proposed to place the propeller concentrically in a tube, the inner surface of which corresponds to the shape of the flow of the air round a propeller in free air, the outer surface of the tube being cylindrical. The interior of the tube may be cylindrical behind the narrowest point. The object being the artificial filling up of the space of contraction of the flow. It is also proposed to fit inside the tube a longitudinally extended partition slightly twisted at its front end in order to neutralise the rotation of the slipstream.

Bombs and Ballistics

400,575. *Improvements in or Relating to Aircraft.* Vojendka Tovarno na Letadla Letov, Letnany, Prague, Czecho-Slovakia. Date, January 21st, 1932. No. 1,895.

This specification refers to a two-seater fighting aeroplane and describes arrangements to enable the rear gunner to have an improved arc of fire. In order to attain this it is proposed to fit the rudder and fin on the under side of the fuselage instead of the upper, so as to improve the rearward arc of fire, and also to fit a step in the lower part of the fuselage near the gunner's seat which, it is stated, enables the rudder and fin to operate in undisturbed air, and also facilitates the fitting of a gun firing below the fuselage. A claim is also made for a similar tail in which the tail skid is attached to a separate fin, while two separate rudders are provided which are secured from below to the outer edges of the tail plane.

404,224. *Improvements in or Relating to the Arrangement of Fixed Forwardly Firing Guns on Aircraft.* Smolik, A., Strosomayerovo nam Prague VII, Czecho-Slovakia. Dated, July 17th, 1933. No. 20,152.

It is proposed, in the case of fighting aircraft carrying more than one pair of machine guns, to arrange that the points of intersection of the fire of the guns of each pair do not lie in a single point, so that each pair has its own point of intersection. It is stated that this arrangement makes the fire more effective when the range is wrongly estimated.

Control of Aircraft

404,269. *Improvements in Aircraft and Control Thereof.* Zap Development Corporation, 230, Park Avenue, City and State of New York, U.S.A. Convention date (U.S.A.), April 3rd, 1931.

It is stated that introducing a variable drag producing element at the underside of an aerofoil and near the trailing edge enables the lift of the wing to be greatly increased and also that the lift will be maintained at high angles of attack. It is also stated that an aeroplane fitted with the arrangement is more stable than usual. Various methods are described for carrying out the scheme. A flap of the normal type hinged to the trailing edge may be used, or a curved plate embedded normally in the wing may be caused to project by rotating a shaft at its centre of curvature. Plates held normal to the airflow may be rotated through 90°, or a sliding plate may be used arranged to slide through guides. Means for controlling the drag producing element are also described.

Engines

403,889. *Improvements in or Relating to Turbines or the Like.* Societe Anonyme des Brevets Leon, 37, Rue du Commerce, Tours (Indre et Loire), France. Convention date, July 6th, 1932.

This arrangement comprises a central rotor with a number of vanes arranged round it, roughly in the manner of a paddle wheel, the vanes themselves are pivoted about their centres and rotate in the opposite direction to the main mechanism at half the speed. Under these conditions it is stated that the vanes will lift for the greater part of their path, but this action may be assisted by an external deflector plate. The arrangement is stated to be suitable for lifting and propelling and also as an air or hydraulic motor, for example, in a windmill.

405,812. *Improvements in or Relating to the Cooling Systems of Internal Combustion Engines on Aircraft.* The Fairey Aviation Co., Ltd., of Cranford Lane, Hayes, Middlesex, and Hollis Williams, D. L., of Hillside, Swakeleys Road, Ickenham, Middlesex. Dated February 27th, 1933. No. 5,955.

It is proposed to utilise the slat used for the formation of a slot in a slotted wing as the cooling system or part of the cooling system for the internal combustion engines used on aircraft. For this purpose the slat is made hollow and arrangements are shown by means of which the cooling fluid, either steam or water, etc., may be circulated through it and condensed steam may be led away, the arrangements consisting of telescopic pipes, etc., so as not to interfere with the normal operation of the slat. The hollow slat may be double-walled so that steam is exposed to the cooling surfaces in thin layers.

Flying Boats

404,052. *Improvements in the Construction of Boats, Pontoons, Aeroplanes, or Other Streamline Bodies.* Edward G. Budd Mfg. Co., 2500, Hunting Park Avenue, Philadelphia, Pennsylvania, U.S.A. Convention date (U.S.A.), June 25th, 1931.

This specification describes a method of construction for streamline bodies, floats, hulls, etc., in which the sides and top and bottom of the body are preformed and are then assembled together with transverse frames. The transverse frames have their curves strongly reinforced by gussets. These frames consist of channel sections with their open sides inwards, which channel sections are flanged so that a cover plate can be fitted. The covers between the longitudinal sections are formed with similar channels. In the case of the frames the cover plate is carried over the gusset and a triangular corner piece is built in. These corner pieces being connected by a cover strip which is attached to outturned flanges. The whole construction is assembled by, preferably, spot welding.

404,059. *Improvements in the Construction of Boats, Pontoons, Aeroplanes and Other Streamline Bodies.*

This specification describes a method of manufacturing boat hulls, etc., of approximately rectangular section by pre-assembling the sides, top and bottom, and then joining these parts by jointing the sheathing of adjacent sections along abutting edges, and by connecting the internal transverse frames. The connecting and joining is preferably done by welding. The sides, top and bottom have outside stringers of channel section fitted longitudinally. The transverse frames are constructed of flanged channel sections, are strongly gusseted on the corners and may be reinforced by diagonal struts internally. The chines are constructed by channel or Z sections arranged so as to form a square section when assembled, and an arrangement is described whereby an opening can be left in the body for the making of internal joints, this opening being eventually closed by a flanged cover plate.

Helicopters

404,257. *Helicopter.* Gretscher, E. W., 41, Wilhelmshavener Strasse, Berlin, N.W.21, Germany. Dated April 4th, 1932. Complete not accepted.

The drawing shows a man operating a helicopter with two rotors by means of pedal gear. The helicopter possesses ascending and descending propeller surfaces comprising pivoted plates, rotating in opposite directions each comprised of a rim of air driving cells. It is stated that the machine requires little power, is safe against falling, is easily steered, can stand still in the air and fly backwards or forwards.

405,539. *Improvements in Arrangements for Starting Flight Requiring no Gliding.* Hirohisa Nishi, 878, Oaza-Kimüdera, Kimüdera-Mura Kaiso-Gun, Wakayama-Ken, Japan. Convention dates, July 4th, 1932; March 4th, 1933; May 3rd, 1933.

This specification describes an aeroplane with which is incorporated an arrangement intended to produce direct lift. This latter arrangement consists of a horizontal propeller collecting air from a duct opening upwards and driving the air downwards. This air is then caused to flow over a wing of crescent shape in plan form and the direct lift is produced by the reaction of the air on this wing. Two superimposed horizontal propellers may be used, rotating in opposite directions.

Model Aircraft

401,400. *Improvements in or Relating to Model Aeroplanes.* Childe, H. N., 41, Alexandra Road, Reading, England. Date, June 13th, 1932. No. 16,686.

A toy monoplane is described in which the longitudinal framework or fuselage comprises two spars connected together at the front and back. The wings are supported by one spar and stayed by struts to the other. It is possible to construct the machine so that it can readily be converted from a high wing monoplane to a low wing, and vice-versa. An application of the method of construction to biplane models is described.

Ornithopters

404,356. *Ornithopter.* Mascow, Hindenburgstrasse 5, Neisse, Upper Silesia, Germany. Dated July 15th, 1932. No. 20,062.

The specification describes an engineless glider on which the wings are oscillated by human power. Inner wings flexibly secured to outer wings are connected with the body by means of springs. On operation by a pedal or pedals the wing can be caused to oscillate. The outer planes are flexibly mounted so that their movement is elastic.

Parachutes

405,693. *Improvements in or Relating to Parachutes.* Quilter, R. C., Bawdsey Manor, Woodbridge, Suffolk, and Gregory, J., 77, Musard Road, Hammersmith, London, W.6. Dated, August 11th, 1932, No. 22,541, and December 16th, 1932, No. 35,680.

It is stated that in the ordinary pack parachute it is usual to pack the pilot parachute beneath the stud-carrying flap or flaps and to rely on elastics or the equivalent to open the flaps and release the parachute when the rip cord is pulled. This arrangement, it is stated, is disadvantageous inasmuch as there is a danger that the tendency of the spring to keep the studs in position may overcome the tendency of the elastics to separate the flaps with the result that the pack will fail to open. It is proposed, to overcome this difficulty, to pack the pilot parachute between the closure flap or flaps of the pack on which the studs are carried and the co-operating flap or flaps carrying the eyelets. The spring of the pilot parachute may consist of a butterfly wire frame adopted to fold with its wings overlying one another when the pilot parachute is packed. Preferably the wire frame consists of an endless wire twisted into a spiral surrounding a tape attached to the canopy of the pilot parachute at the junction of the wings of the frame.

The preferred form of parachute is provided with a skirt portion which is stated to reduce the tendency of the parachute to roll, and the construction and packing of the proposed parachute are described in detail.

REVIEW

"Les Appareils à Fil Chaud"

By E. G. Richardson. (Gauthier-Villars, Paris. 20 Frs.)

This book is the outcome of an invitation lecture on hot-wire instruments and their applications given by the author at the Institut de Mécanique des Fluides of the University of Paris two years ago. The lecture notes have been elaborated into a sixty-page book of two parts. The first deals with the theory and types of hot-wire anemometers, together with the practical precautions and corrections necessary when the instruments are used under special conditions, *e.g.*, in a rapidly fluctuating air current. The second part gives a number of applications in which these instruments are particularly useful; flow round models, delineation of vortex systems, aerial sound waves, etc. The book also contains chapters on the measurement of the velocity of liquids and the density and pressure of a stationary fluid. A very full bibliography of sixty-two references is given in an appendix.

The 571st Lecture read before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

Sixth Meeting, First Half, 69th Session

The Sixth Meeting of the first half of the 69th Session of the Royal Aeronautical Society was held at the Royal Society of Arts on Thursday, December 14th, 1933. In the chair: Mr. C. R. Fairey, M.B.E., F.R.Ae.S., President of the Society.

The Chairman: He had a formal but very pleasurable duty to perform before introducing the author of the paper that was to be read. As most of the members knew, the membership of the Society at the present time, excluding the branches, exceeded 1,500, but of these only 12 were Honorary Fellows. Honorary Fellowship of the Society was a very jealously guarded honour and election to this grade had not been made for some years. The present Honorary Fellows included such names as Professor Prandtl, Dr. F. W. Lanchester, Major Baden-Powell—their oldest member— and Lord Wakefield, together with several other very distinguished people. Under Rule 41 the Council had power to recommend to the members of the Society at such a meeting as this the election of further Honorary Fellows and at the last meeting of the Council two names were unanimously put forward which he now had the privilege of recommending to the members for election to Honorary Fellowship. The first was that of Mr. Griffith Brewer, who had been a member since 1903, over 30 years, or getting on for half the life of the Society. Mr. Brewer, of course, was well known in aviation apart from the Society and he was the first man to fly with the famous Brothers Wright. Mr. Brewer had been a Vice-President of the Society and had rendered great service to the Society on the Council. The second name was one of the most, if not the most, distinguished in aviation, viz., Mr. Orville Wright, and there was no need for him to say anything further by way of recommendation. He therefore proposed to the meeting that Mr. Griffith Brewer and Mr. Orville Wright be elected Honorary Fellows.

The recommendations of the Council were unanimously carried.

Introducing the lecturer of the evening—Dr. Leslie Aitchison—the Chairman said there was no subject of greater interest to the aeronautical engineer or the aircraft designer than that of light alloys and a lecture on that subject was to be given by a very distinguished metallurgist; indeed, they could have had none better for this purpose. He understood that some of the matter which Dr. Aitchison was to put forward was controversial and if that were so, all the better. Following war service with the Royal Naval Air Service, Dr. Aitchison had been metallurgist to the Air Board and had been retained as consulting metallurgist by the Air Ministry. For the past eight or nine years he had been Superintendent of Messrs. James Booth and Co.

The paper was then presented.

LIGHT ALLOYS FOR AERONAUTICAL PURPOSES WITH SPECIAL REFERENCE TO MAGNESIUM

BY

LESLIE AITCHISON, D.Met., B.Sc., F.I.C.

To deal effectively in the course of a single lecture with the subject of light alloys for aircraft is, to-day, practically an impossibility. Actually, the various alloys of aluminium that are put forward for consideration by the aeronautical engineer do not vary amongst themselves to such an enormous extent as to make one or other of over-riding interest, and much the same might be said of the alloys of magnesium. Despite this position, so much of interest is occurring in both fields, and so many alloys are being put forward having some characteristic or another of real interest, that the aircraft engineer, and in fact any other engineer, could readily be excused if he felt somewhat nonplussed when he surveyed the multitude of materials that are offered for his employment. I am relieved, therefore, that your Council decided that this lecture should give special prominence to the alloys of magnesium. I am assuming that by this they mean those alloys which consist of magnesium in a great preponderating proportion, but I feel that the time is appropriate also to make some reference to those alloys which consist principally of aluminium, but which possess definitely useful properties in consequence of the presence in them of certain relatively small proportions of magnesium. I propose, however, first to consider the alloys rich in magnesium, and will endeavour to provide some data of a rather fundamental type which may be of definite service to the aeronautical engineer when he is engaged in comparing the relative importance and value of the magnesium alloys made available to him in commerce.

The metal magnesium itself, when of commercial purity, has certain uses, but, like most pure metals, its mechanical properties are so inferior as to make the material of the slightest value for constructional purposes. The nature of these properties can be seen from the figures in Table I, where, alongside the values for magnesium, are also shown the corresponding figures for aluminium and copper, which are two other typical pure metals used industrially in considerable quantities and can therefore serve as a valuable basis for comparison.

TABLE I.

PROPERTIES OF PURE MAGNESIUM, ALUMINIUM AND COPPER (ROLLED AND ANNEALED).

	Magnesium.	Aluminium.	Copper.
Density	1.74	2.71	8.93
Maximum Stress, tons/in.^{2}	11.0	6.0	14.0
Elongation, per cent.	5.0	40	60
Reduction of Area, per cent.	6.0	80	75
Brinell Hardness	33	24	38
Specific Tenacity	6.3	2.3	1.56

Naturally, in view of the mechanical properties shown in Table I, efforts have been made to produce alloys of magnesium which will possess mechanical properties of a valuable order, and it seems that the first step of interest should be to demonstrate something of the fundamental possibilities in this direction.

It is obvious to everybody that the main interest attaching to magnesium consists in its exceedingly low specific gravity. Probably very little engineering interest would be taken in this metal were it not the " lightest " known, and consequently it becomes practically impossible to make any alloying additions to

magnesium without affecting the density in an adverse manner. The inference from this position is that if heavy elements are to be alloyed with magnesium, they ought to be employed as sparingly as possible. This will have a definite effect upon the field in which useful aeronautical alloys will be found.

Another factor which definitely affects the production of useful alloys of magnesium is that this metal differs from most other well known and recognised materials of construction in its crystalline character. Iron, aluminium, copper and nickel, which may, I suppose, be taken as the other recognised bases of the " engineering metals," all crystallise in the cubic system. Magnesium does not, but consists of crystals conforming to the hexagonal system. This fact has a very big bearing upon the mechanical and metallographic behaviour of magnesium generally, but it naturally also has a very definite bearing upon the subject of alloying. It would naturally be assumed that those elements which could most usefully be added to magnesium would preferably be those which also crystallise in the hexagonal system. Of the metals which are available in general industry, only two, other than magnesium, crystallise in this particular system—namely, cadmium and zinc—and it seems preferable, therefore, to examine first of all the effect upon the mechanical properties of magnesium produced by adding proportions of zinc and/or cadmium to it.

In Table II, figures are set out to show the effect upon the mechanical properties of magnesium of additions of certain proportions of zinc,

TABLE II.

THE INFLUENCE OF DIFFERENT PROPORTIONS OF ZINC UPON THE MECHANICAL PROPERTIES OF MAGNESIUM (EXTRUDED).

Zinc per cent.	Maximum Stress tons/sq. in.	Elongation per cent.	Reduction of Area per cent.
1.69	13.9	13.2	35.8
1.98	14.3	13.8	31.6
3.00	15.0	16.7	31.6
4.93	17.8	15.0	23.1
5.73	18.2	16.4	24.7
6.35	19.0	17.6	23.2
6.65	18.2	15.6	27.3
7.34	17.9	18.4	33.8
11.02	18.9	15.0	22.0

whilst in Table III are shown the corresponding values resulting from the addition of varying proportions of cadmium.

TABLE III.

THE INFLUENCE OF DIFFERENT PROPORTIONS OF CADMIUM UPON THE MECHANICAL PROPERTIES OF MAGNESIUM (EXTRUDED).

Cadmium per cent.	Maximum Stress tons/sq. in.	Elongation per cent.
0	11.5	10.5
5.5	15.5	8.7
8.5	15.25	9.9
13.0	15.25	9.2

It will be noticed that, in each series of binary alloys, the properties of the richer alloys are considerably better than those possessed by the pure metal itself, but even so they are not tremendously striking, and it is clear that it will be necessary to add some other metals—in other words to produce ternary alloys—if materials possessing really useful mechanical properties are to emerge.

To produce a ternary alloy, a departure from the metals which crystallise in the hexagonal system must be made, and the importance of specific gravity must then be remembered in making a choice of the third metal. Obviously, then, it is important to ascertain first of all exactly what effect is produced upon the mechanical properties of magnesium when aluminium in suitably graded proportions is added to it. The effects of such straightforward additions of aluminium are shown in Table IV.

TABLE IV.

THE INFLUENCE OF DIFFERENT PROPORTIONS OF ALUMINIUM UPON THE MECHANICAL PROPERTIES OF MAGNESIUM (EXTRUDED).

Aluminium per cent.	Maximum Stress.	Elongation per cent.	Reduction of Area per cent.
2.5	14.3	12.5	29
7.74	20.8	12.0	19.0
8.17	19.7	12.0	16.0
8.51	19.9	8.5	16.0
9.17	21.3	8.0	15.0
9.35	19.8	8.5	15.0
10.6	21.6	6.2	13.0
11.77	23.4	2.6	4.0
12.22	21.6	5.0	7.0
12.5	24.2	2.0	4.4
13.14	20.0	1.0	5.7
19.19	20.6	—	—

From the test figures in this table it emerges that, in general, the beneficial effect of aluminium upon the strength properties of magnesium is quite considerable, but that the ductility factors are affected rather adversely. In view of the detrimental effect of aluminium upon the ductility, it becomes desirable to investigate the possibility of securing the strength benefits imparted by additions of aluminium, and at the same time to minimise, if possible, the losses in ductility, always ensuring that, as far as possible, the density of the resulting alloys shall not be unduly higher than that of magnesium. With this end in view, careful investigations have been made to determine the effect of adding aluminium plus zinc in one case, and aluminium plus cadmium in the other, and the mechanical effects of these additions are set out in Tables V and VI respectively.

TABLE V.

THE INFLUENCE UPON THE MECHANICAL PROPERTIES OF MAGNESIUM OF DIFFERENT PROPORTIONS OF ALUMINIUM, PLUS ZINC (EXTRUDED).

Aluminium per cent.	Zinc per cent.	Maximum Stress tons/sq. in.	Elongation per cent.	Reduction of Area per cent.
1.22	1.26	13.8	17.3	47.0
3.96	1.29	15.8	17.6	36.15
2.42	1.87	16.1	16.0	35.2
1.58	2.48	15.5	17.4	40.8
5.38	1.52	18.0	17.1	28.25
3.75	3.10	18.1	20.0	34.65
2.34	4.06	17.6	21.3	39.9
8.04	2.15	21.6	13.5	17.0
5.53	3.90	22.5	16.25	17.0
9.97	2.33	22.7	11.5	13.5
6.14	4.12	22.0	12.7	18.5
3.75	7.85	19.0	11.0	13.5
4.97	3.08	19.8	16.5	24.60
2.95	4.45	19.4	15.5	13.55
4.86	3.69	20.8	15.75	21.56
6.17	3.05	20.0	17.0	20.9
5.22	5.08	21.0	17.2	25.2

TABLE VI.

THE INFLUENCE UPON THE MECHANICAL PROPERTIES OF MAGNESIUM OF DIFFERENT PROPORTIONS OF ALUMINIUM, PLUS CADMIUM (EXTRUDED).

Aluminium per cent.	Cadmium per cent.	Maximum Stress tons/sq. in.	Elongation per cent.	Reduction of Area per cent.
9.47	1.25	22.1	8.7	9.76
10.28	1.96	22.0	12.6	17.3
9.70	2.08	22.4	10.56	14.7
9.50	3.76	22.05	11.2	16.25
12.44	1.13	22.9	7.2	6.0
12.99	2.10	23.0	4.2	5.9

Before examining critically the results which have been obtained in these various ways, it is desirable to see whether any of the other binary systems similar to that with aluminium yield results that would be of value. For this purpose two elements have been investigated rather carefully, namely manganese and silicon. It has been found that the presence of manganese in magnesium alloys confers advantages of a certain character quite apart from any that may be associated with the mechanical properties of the resulting material. This is important, as the effect of manganese upon the mechanical properties of magnesium is not really at all striking, as can be seen from the test values obtained from a series of binary alloys and shown in Table VII.

TABLE VII.

THE INFLUENCE OF MANGANESE ADDITIONS UPON THE MECHANICAL PROPERTIES OF MAGNESIUM (EXTRUDED).

Percentage Added Metal.	Maximum Stress tons/sq. in.	Elongation per cent.
0.18	13.7	6.0
0.41	13.6	5.2
0.75	13.4	4.3
0.82	13.4	4.0
1.13	13.0	3.6
1.52	13.2	4.0
1.94	13.1	3.5
2.60	13.3	3.6

The addition of silicon produces rather more definite effects upon the properties, and these can be well seen from the figures given in Table VIII.

TABLE VIII.

THE INFLUENCE OF DIFFERENT PROPORTIONS OF SILICON UPON THE MECHANICAL PROPERTIES OF MAGNESIUM (EXTRUDED).

Silicon per cent.	Maximum Stress tons/sq. in.	Elongation per cent.	Reduction of Area per cent.
0.04	11.6	18.8	31.3
0.16	14.2	10.7	14.3
0.56	14.9	7.3	13.4
0.93	16.5	7.3	11.4
1.01	17.1	7.6	11.0
1.26	15.7	6.7	9.2
1.73	15.65	6.2	8.5
2.19	14.4	4.2	5.9

It may be desirable at this stage to review the results which have been obtained from this brief summary of the mechanical possibilities of alloying different elements with magnesium, and to compare the results obtained with those that can be obtained from the best available alloys of aluminium. It is obviously necessary to make the comparison between the magnesium series of alloys and the aluminium series upon cast alloys separately from those in the wrought condition. For the former section a satisfactory basis for comparison exists in such alloys as L8, L11, the silicon alloys like " Alpax " or " Silumin,"

and in " Y " alloy (both as cast and heat-treated). In Table IX typical properties for these particular alloys are set out,

TABLE IX.

THE MECHANICAL PROPERTIES OF TYPICAL ALUMINIUM ALLOYS
" AS CAST."

Alloy.	Proof Stress. tons/sq. in.	Maximum Stress. tons/sq. in.	Elongation per cent.	Brinell Number.	Specific Tenacity.	Form.
2L8	5.0–6.0	10–11.5	1–2	68–73	3.3/3.8	Chill
Sp. Gr. 3.0 ...	4.0–4.0	8.5–10.5	0–0.5	70	2.8/3.5	Sand
3L11	6–8	9–11	4–3	55–60	3.1/3.8	Chill
Sp. Gr. 2.9 ...	5–6	7.5–8.5	2.5–1.5	50–55	2.6/2.92	Sand
Al-Si	4–5	10.5–11.5	10–5	45–55	4.0/4.4	Sand
Sp. Gr. 2.6 ...						
"Y" Alloy ...		13.0	1.5	92	4.6	Chill
Sp. Gr. 2.80 ...		10.0	1.0	87	3.6	Sand
"Y" Alloy ...		20.0	2.5	100	7.1	Chill
Sp. Gr. 2.80 ...						(Heat-treated)

and certain figures of merit are included which are simply the ratio between the maximum stress and the density. This criterion, known as the specific tenacity, is open to certain objections if taken too literally as a figure of merit, but from the straightforward point of view of the constructor, it certainly provides something of real value when determining the lightest method of producing a particular part having a given strength. In Table X are displayed the corresponding properties of typical magnesium alloys resulting from the principles shown above, in the cast condition, and the figures for the specific tenacity are again quoted for this series of alloys.

TABLE X.

THE MECHANICAL PROPERTIES OF TYPICAL MAGNESIUM ALLOYS
" AS CAST."*

Material.	Yield Point.	Maximum Stress. tons/sq. in.	Elongation.	B.H. No.	Specific Tenacity.
Elektron AZG (Sand) ...	6.0–7.0	9–11	5–3	45–55	5.0 /6.1
,, ,, (Chill) ...	6.0–7.0	13–15	6.0	50–60	7.15/8.25
Elektron A8 (Sand) ...	6.0–7.0	9–11	5–3	45–55	5.0 /6.1
,, ,, (Chill) ...	6.0–7.0	13–15	10–6	50–60	7.15/8.25
Elektron V1 (Chill) or (Pressure)	7.0–8.0	9–12	4–2	65–70	5.0 /6.6

Turning now to the wrought alloys, an equally interesting position is revealed, but before actually quoting the test values given by the materials in this form, it is rather necessary to make some reference to certain peculiar characteristics of magnesium, and most particularly of magnesium alloys, as they explain in some measure the variable properties put forward for the alloys in the different forms in which they may be made use of by the aeronautical engineer.

The first characteristic to notice is that, *in a general sense*, the mechanical properties of alloys of magnesium are not capable of improvement by heat-treatment in the same way as occurs with duralumin or its derived alloys. This means that such strength as the magnesium alloys possess is present in virtue of two things which are quite distinct. The first controlling factor is the actual intrinsic strength and ductility of the alloy, due to the metallographic effect of inserting atoms of a second, or second and third, element into the crystallographic lattice of magnesium. The second factor is that of cold work, and this particular factor must be examined rather carefully because the capacity possessed by magnesium alloys for absorbing cold work is decidedly and definitely limited. Naturally no such problems as this arise in connection with cast alloys.

* The Proof Stress (0.1 per cent. of strain) of these castings varies from 5.5 to 7.0 tons per square inch.

It has already been stated that magnesium differs from the other principal engineering materials of construction by crystallising in the hexagonal and not the cubic system, which means that its crystals have four axes of symmetry and not three. This fact has a very definite bearing upon the capacity for distortion of magnesium and its alloys, and also has a very definite bearing upon the mechanical properties following from the crystalline orientation in any given piece of material. There is no time in this lecture to deal exhaustively with this subject, but merely to note the fact and to study the consequences.

The practical effect of this fact in general terms is that it is possible to distort a single crystal of pure magnesium to a very considerable extent, but only in certain directions relative to the crystalline axes. A limit to plastic distortion is fairly quickly reached, however, in any piece of commercial material consisting, as it naturally does, of a composite agglomeration of crystals orientated in a variety of directions in relation to the outside dimensions of the piece. This limit is fairly marked in the pure metal, but in the alloys is reached much more quickly, and simply means that the possibility of applying cold work to magnesium alloys, particularly to those containing any notably high proportion of alloying elements, is definitely slight. From this there emerges a corollary that any working or extensive shaping of the metal (if it is to be accomplished at all) must be carried out at temperatures relatively much above atmospheric.

Fortunately for all concerned, at temperatures over 225°C., the capacity of magnesium and its alloys to suffer distortion increases considerably, and the capacity for plastic working of those alloys which contain only a small proportion of alloying elements is reasonably good at these relatively high temperatures. Nevertheless, an increase in the proportion of elements crystallising in the cubic habit present in the magnesium alloy very quickly diminishes the possibility of distortion of the resulting material. Even at these elevated temperatures, the rate at which the metal can be worked or distorted is very different from that ordinarily experienced by the forgeman or the metal roller. This is particularly true of those alloys which contain higher proportions of the alloying elements, and the rate of deformation must be very small indeed when high percentages of, for instance, aluminium are present in the alloy.

In view of these facts, it is desirable to quote the mechanical properties of representative magnesium alloys in a variety of forms produced by working hot. In Tables XI, XII and XIII such figures are given for representative magnesium alloys, and values are included for the specific tenacity of the alloys in these different conditions.

TABLE XI.

The Mechanical Properties of Wrought Magnesium Alloys (Rolled Sheet).

Alloy.	Condition.	Proof Stress. tons/sq. in.	Maximum Stress. tons/sq. in.	Elongation per cent.	V.P.N.	Specific Tenacity.
Elektron AM503	As rolled	10.0	15.5	5.0	46	8.6
,,	Rolled and annealed	7.0	12.0	7.0	40	6.7

TABLE XII.

The Mechanical Properties of Wrought Magnesium Alloys (Extruded).

Alloy.	Form.	Proof Stress. tons/sq. in.	Maximum Stress. tons/sq. in.	Elongation per cent.	V.P.N.	Specific Tenacity.
Elektron AM503	3½in. Bar	7.3	14.4	6.5	43	8.3
,,	16SWG. Tube	13.5	18.8	4.0	48	10.4
Elektron AZM	⅝in. Bar	15.3	21.2	15.0	66	11.6
,,	2in. Bar	10.8	20.4	13.0	67	11.2
,,	½in. Angle	12.5	20.5	18.5	66	11.2
,,	10SWG. Tube	18.7	21.9	16.0	—	11.9

TABLE XIII.

THE MECHANICAL PROPERTIES OF WROUGHT MAGNESIUM ALLOYS (FORGED).

Alloy.	Form.	Proof Stress. tons/sq. in.	Maximum Stress. tons/sq. in.	Elongation per cent.	Specific Tenacity.
Elektron AZM	6in. Bar	11.6	19.0	13.0	10.3
,,	1in. Bar	11.2	19.0	19.0	10.3
Elektron AZ855	Airscrew	15.6	21.4	8.5	11.7
,,	5½in. Bar	12.4	22.2	10.5	12.1
,,	2in. Bar	15.4	22.0	13.0	12.0
,,	Upended (Radial)	14.8	21.6	9.0	11.8

In Table XIV are set out for comparison the values for some recognised wrought alloys of aluminium, corresponding to those given for the magnesium alloys in Table XII.

TABLE XIV.

THE MECHANICAL PROPERTIES OF TYPICAL WROUGHT ALLOYS OF ALUMINIUM (EXTRUDED AND HEAT TREATED).

Alloy.	Proof Stress. tons/sq. in.	Maximum Stress. tons/sq. in.	Elongation per cent.	Specific Tenacity.
Duralumin	17.8	25.0	18.7	8.91
" Y " Alloy	14.5	24.0	18.0	8.60
Super Duralumin ...	23.0	30.0	12.0	10.7
RR56	22.0	27.0	12.0	9.47

From the figures given in the last four tables, it becomes clear that if the specific tenacity is accepted as a criterion of the merit of an alloy from the standpoint of the constructional engineer, the alloys of magnesium possess properties which make them definitely comparable, and indeed competitive, with those of the wrought aluminium alloys.

Before leaving the subject of the mechanical properties of the magnesium alloys, it seems desirable to make some reference to their resistance to fatigue and also to the properties of the alloys at elevated temperatures. Once again it seems most desirable to refer to the properties of the aluminium alloys as a comparison, and in Table XV are given the fatigue values at room temperatures of various wrought alloys of aluminium and of typical magnesium alloys.

TABLE XV.

FATIGUE LIMITS OF WROUGHT ALUMINIUM AND MAGNESIUM ALLOYS (WOEHLER VALUES—20 MILLION REVERSALS).

Pure Magnesium.	Elektron AZM.	Duralumin B.	Duralumin F.	RR56.
Tons/in.²	Tons/in.²	Tons/in.²	Tons/in.²	Tons/in.²
±4.46	±8.9	±9.5	±11.5	±10.7

In giving figures for the properties of these alloys at high temperatures, it is difficult to avoid criticism as to the basis of choice. For simple comparisons " quick tests " have been chosen, and the values quoted in Table XVI may be taken as a fair representation of the strength of the chosen materials when tested in this way. As before, the values for aluminium alloys are given alongside those for the magnesium alloy.

TABLE XVI.

TENSILE STRENGTHS AT ELEVATED TEMPERATURES OF WROUGHT ALLOYS OF ALUMINIUM AND OF MAGNESIUM.

Temperature °C. of Test.	Elektron AZ855.	Duralumin.	Y Alloy.	RR56.
	Maximum Stress, tons/sq. in.			
20	20.0	26.5	25.0	27.0
100	16.5	25.5	23.5	24.0
150	13.7	22.5	22.5	22.5
200	12.0	20.0	21.5	21.0
250	6.0	18.5	21.0	20.5
300	—	13.0	16.5	15.0
350	—	8.0	13.0	10.0

What has been written above gives very briefly an indication of the present position regarding the mechanical properties possessed by the alloys of magnesium in various conditions, and it is perfectly clear from these particulars that in both the cast form and the wrought form magnesium alloys possess properties which render the materials very useful indeed to the aeronautical engineer. It is of course clear that by no process of alloying is it possible to alter in any very useful degree the rather low value of Young's modulus possessed by magnesium and its alloys, and it is rather a noteworthy fact that the ratio of density to elastic modulus is approximately the same for magnesium and its alloys as it is for the other two basic engineering metals—namely iron and aluminium. The figures in question are shown in Table XVII.

TABLE XVII.

RATIO OF MODULUS OF ELASTICITY TO DENSITY OF IRON, ALUMINIUM AND MAGNESIUM.

Material.	Elastic Modulus tons/sq. in.	Density.	Elasticity/ Density.
Iron	12,500	8.00	1562.5
Aluminium	4,460	2.70	1651.8
Magnesium	2,680	1.74	1655.1

Mechanical properties, important though they be, do not, however, exhaust the interest of the aeronautical engineer in any given metal, and there are certain other characteristics of the magnesium materials which demand some attention. The two properties in particular which need most examination are:—

(*a*) The possibilities of welding the alloys, and

(*b*) The resistance of the materials against corrosion.

With reference to the former, it has now been established definitely that when once the necessary technique has been acquired, the production of welds in magnesium alloys, particularly in those which contain but low proportions of secondary elements, can be effected with just as much regularity and satisfaction as is possible with aluminium. The main requisites for producing a satisfactory weld in magnesium alloys may usefully be summarised.

The first essential is a skilled welder, and one trained rather in the welding of aluminium and its alloys than in the welding of steel. The process almost invariably employed in the welding of elektron is the oxy-acetylene process, and consequently the second essentials are the use of the right flux and the right welding rod. Fortunately both these requisites are standardised and commercially available. It is only necessary to specify the composition and form of the alloy it is required to weld.

Before welding castings it is necessary to preheat them to a temperature of 250/300°C., the latter figure representing the absolute maximum. After this preheating, the welds should be prepared as for other metals by bevelling the edges to be joined, in a suitable manner. The welding is then carried out as for aluminium alloys, except that it is of first importance during the welding process to eliminate all flux from beneath and within the added metal. The finishing layers of the weld always contain a certain amount of occluded flux, and therefore at least a quarter of an inch of surplus weld should be made so that these flux inclusions are completely removed during the subsequent fettling process. Where possible, the welded joints should be annealed.

The " after treatment " of welds is of great importance. When the weld has been fettled, it should be washed and scrubbed with a wire brush in a bath of hot water containing 15 per cent. of potassium bichromate. After this treatment it should be rinsed and immersed for one minute in a 15 per cent. nitric acid bath to which has been added a small proportion of potassium dichromate.

The most satisfactory welds in sheet or strip are made in the alloys containing but small proportions of the added element—such as the elektron alloy

AM503. The welding rod in this case is of the same alloy. Welders skilled in the art of welding aluminium sheet and strip, given the right flux, will find very little difficulty in mastering the welding of such materials. They are, of course, much stiffer than pure aluminium sheet, and the first thing the welder notices is that they require—particularly in complicated welds—more support than is necessary for aluminium. If, on a given length of run, clamping and tacking is done about twice as frequently as is common with aluminium, then this difficulty is completely overcome.

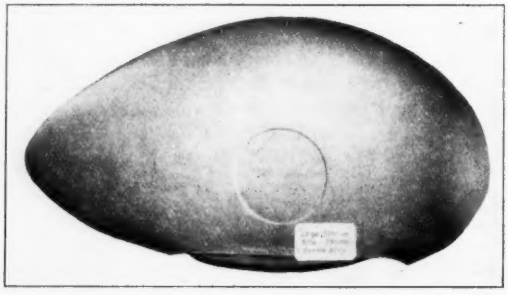


FIG. 1.
Elektron landing wheel spat,
6ft. 7in. long × 3ft. 1in. high, weight 19.8lbs.

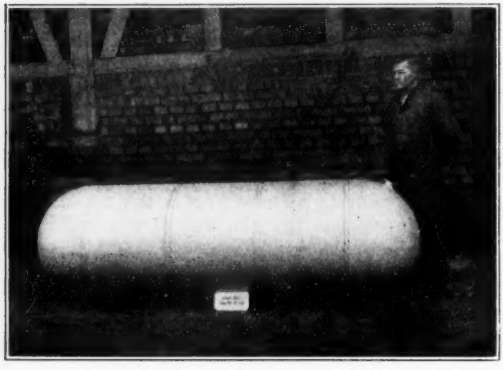


FIG. 2.
Elektron welded petrol tank,
capacity 230 galls., weight 31.5lbs.

What has been said about the meticulous removal of flux from the weld in the case of castings applies far more in the case of sheet and strip. This is because in butt welding or seam welding sheets and strips, relatively little new metal is added, the object being to fuse the two adjacent surfaces with the addition of the minimum new metal. There can be no question here of allowing excess thickness to fettle off afterwards, and it can be said that the art of welding magnesium alloy sheets is the art of eliminating flux. Finished welds should be first brushed off with hot water containing 15 per cent. potassium bichromate until all traces of flux are removed.

Welds in sheet are usually hammered at this stage, this being done when the metal is at a temperature of 270-320°C. This procedure is adopted until all the welds are complete on the particular part under construction, when it is then chromated by one or other of the processes which are set out below.

Some typical welded structures are shown in Figs. 1, 2, 3 and 4.

In all probability, the subject of the resistance of the magnesium alloys to corrosion is the most interesting of all to the aeronautical engineer, and it is most important to determine the exact situation. It should be realised at the start that magnesium and its alloys are definitely more prone to suffer from corrosion by atmospheric moisture or saline solutions than are the alloys of aluminium. On the other hand, magnesium is able to offer a much greater resistance even than aluminium to the effect of certain types of corrosive reagent. As a particular example, magnesium and its alloys resist alkalies exceedingly powerfully and almost indefinitely, whereas under the same circumstances aluminium is attacked at a great rate.

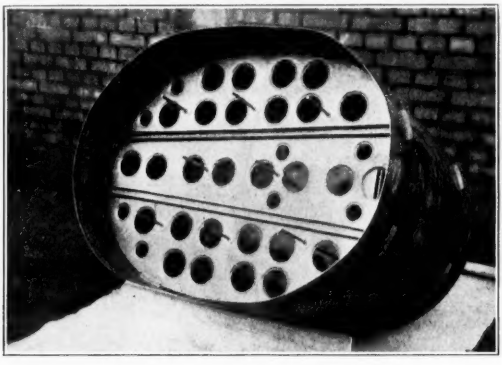


FIG. 3.
Elektron petrol tank, showing welded construction.

In thinking of the corrosion resistance of any metal, one hears far more about the failures than the successes, and the magnesium alloys suffer to-day from a reputation earned in the early days when much less was known than is known now about their constitutional stability and the precise effects of added elements upon the dependent corrosion resistance. We have all heard of the times, a few years ago, when magnesium alloys occasionally disappeared altogether—or were found, months later, to have lost their initial geometrical form and become ugly amorphous heaps of wet grey dross. Fortunately, those days are over and the modern magnesium alloy does not now behave in that way, due, in the main, to two factors—firstly, that the alloys are now themselves metallurgically more perfect and more stable than was possible hitherto, and secondly, that metallurgists have learned how to protect them. The two factors have combined to alter the situation regarding the corrosion of magnesium alloys altogether.

It is desirable to examine this matter in its proper perspective. If, by corrosion, is meant inland atmospheric corrosion, there is really very little fear of dangerous attack on the magnesium alloys, even when unprotected. The position in this matter cannot be better stated than by quoting Dr. Bengough

and Mr. Whitby, who, in their paper " Magnesium Alloy Protection by Selenium and other Coating Processes,"* say, " in Berlin 'bus wheels of elektron have been in use for some years and serious attack has been recorded only when salt was used for melting snow in the streets. At Teddington vertically suspended specimens of AZM, Z3 and 66 have been exposed to the weather in a field for nearly a year; on the AZM specimens a patchy film, showing interference colours, has been formed; on Z3 a small amount of greyish-white deposit has formed, and alloy 66 has turned dull grey, but there is no serious corrosion on any."

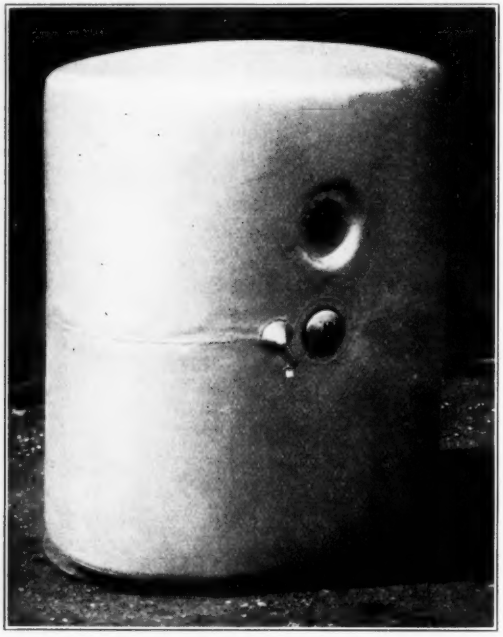


FIG. 4.
Welded elektron tank,
capacity 900 galls., weight 55lbs.

" In addition to these bare specimens, others were similarly exposed after treatment, . . . altogether 162 specimens have been exposed to the weather in the suburban conditions of Teddington for about a year, but not one has seriously corroded."

Cast elektron has the advantage in corrosion resistance over wrought elektron that all castings have over all wrought products in any material. The actual cast skin is itself a protective film of great durability, and elektron castings, even when unprotected, are definitely more resistant to atmospheric corrosion than many of the established and widely used cast aluminium alloys. Methods of protection are therefore better stated in terms of wrought alloys, which, in

* Jnl. Inst. Met., Vol. XLVIII., No. 1, 1932, pp. 147-163.

most cases, are robbed of their natural high temperature oxide film by the working processes essential for their production.

Since for aeronautical purposes the acceptable standard of corrosion resistance is set exceedingly high, the question with magnesium and its alloys becomes definitely one of how best to protect them. This problem has been tackled in various ways, but essentially when viewed through aeronautical spectacles all the methods which have been devised are really intended to create on the surface of the magnesium alloy a layer (which is both very adherent and as free as possible from porosity) on to which paint or varnish can satisfactorily be applied. Probably the oldest method which can be regarded as at all satisfactory is that of chromating as developed by I.G. Farbenindustrie Aktiengesellschaft and is carried out in the following manner:—

The parts are first degreased thoroughly by washing in petrol or dipping in caustic soda. Then they are immersed for 10 to 40 seconds in a solution of nitric acid (1.25 Sp. G.), 100 gallons; water 100 gallons and sodium bichromate 380lbs. (or proportionately for any required quantity). A thorough rinse in running water must be given to the parts before entering the finishing bath, which is a hot solution of ½ per cent. sodium bichromate in water. In order to ensure quick and efficient drying off, it is important that this bath be worked at a temperature of 65° to 75°C. The treatment imparts to the alloy a very pleasing golden colour and ensures some definite degree of protection against inland atmospheric exposure and, further, provides a good basis for paints or varnishes.

A development of the chromating process has been worked out by Mr. Sutton of the R.A.E. and this modification provides a finish which is in itself more attractive than that provided by the chromating dip. The most important details of this modified process are as follows:—

The parts are first pickled in ten per cent. nitric acid solution, and, after washing in running water, are placed immediately in the following bath, which is maintained at a temperature of 95° to 100°C.

1.5 per cent. potassium dichromate.	}	In water.
1 ,, ,, alum.		
0.5 ,, caustic soda.		

The time of immersion may be from one to ten hours, depending upon the mass of the charge and the alloy of which it is composed. The process gives to elektron alloys a delightful patina, varying in colour from " field grey " to the richest ebony. Although it takes a good deal longer than the chromating process given above, it has a very useful advantage over the former process, in that it can be applied to highly finished and ground parts without causing any appreciable dimensional change.

A good deal of work has recently been carried out by Dr. Bengough in the development of a protective coating based upon the use of metallic selenium. It is found that if a magnesium alloy is dipped at atmospheric temperatures in a solution consisting of a 10 per cent. solution of selenious acid in water to which has been added from 0.1 to 0.5 per cent. of sodium chloride, the alloy becomes coated with a layer of metallic selenium. Against certain reagents, the selenium coating itself presents satisfactory resistance to corrosion, but it is not really valuable against very active conditions, such as marine atmospheres. Like the chromates, however, it provides a basis for the attachment of paints and varnishes, which is probably the most that can really be claimed for the two previous methods described.

The actual effect of these three methods on protecting magnesium against corrosion—without the use of a paint or varnish—can be estimated from the test values given in Table XVIII.

TABLE XVIII.*

RESISTANCE OF A MAGNESIUM ALLOY (ELEKTRON AZM) TO SEA-WATER SPRAY WHEN TREATED BY VARIOUS PROCESSES.

Treatment.	Maximum Stress tons/sq. in.	Elongation per cent. on 2in.
1. Selenised only	18.4	14.0
2. Selenised and painted, after storing for four months	18.6	14.0
3. As 2, but after four months' sea-water spray ...	16.7	6.0
4. R.A.E. chromate process only	18.9	15.5
5. As 4, but painted and stored for four months ...	19.1	13.5
6. As 5, but after four months' sea-water spray ...	12.8	2.5
7. I.G. chromate process only	18.6	15.0
8. As 7, but painted and stored for four months ...	18.8	15.0
9. As 8, but after four months' sea-water spray ...	16.1	5.0
10. Untreated	19.3	18.0
11. As 10, but painted and stored for four months ...	18.7	12.0
12. As 11, but after four months' sea-water spray ...	11.8	1.5

* Bengough and Whitby, loc. cit.

It would seem to be desirable to indicate a few of the purposes to which the alloys of magnesium, whose properties have been brought out above can profitably be put. In formulating such a schedule of applications, notice has been taken of the experience on the Continent of Europe and also in America, and various components from the schedule are illustrated in the Figs. 3 to 10.

Airscrews (adjustable pitch)	Made from	Forgings.
Petrol Tanks	,, ,,	Sheet; Extruded Sections; Tubes.
Cowlings and Fairings (Engine, Fuselage, Wings)	,, ,,	Sheet; Extruded Sections; Tubes.
Landing Gear, Wheels, Wheel Mountings, Tail Skid Mountings, Brake Shoes, etc.	,, ,,	Castings; Forgings; Extruded Sections; Sheets.
Ribs	,, ,,	Extruded Sections; Tubes; Sheet.
Rudder Frames and Ribs	,, ,,	Extruded Sections; Tubes; Sheet.
Aileron Frame and Ribs complete ...	,, ,,	Extruded Sections; Tubes; Sheet.
Seats—Pilot and Passenger	,, ,,	Tubes; Extruded Sections; Sheet; Castings.
Dash Boards and Dash Board Mountings and Brackets	,, ,,	Castings; Extruded Sections; Sheet.
Luggage Carriers and Brackets ...	,, ,,	Tubes; Castings; Sheets.
Engine Parts—Bearing Housings, Cam Shaft Bearing Brackets and Housings, Sumps, Pump, Magneto and Accessory Brackets and Mountings	,, ,,	Forgings; Castings, and parts machined from Extruded Bars and Sections.
Door Frames, Wall and Bulkhead Panelling	,, ,,	Sheet; Extruded Sections.
Ladders, Steps, etc.	,, ,,	Sheet; Extruded Sections.

Of these applications, perhaps the one that seems to call for the most comment is that of airscrews. The properties have already been shown of the magnesium alloys developed for this purpose, namely, a specific tenacity of not less than 10½ to 11½, a modulus of elasticity of about 5.6 million lbs./square inch, and, tested on actual airscrew blades forged in this country, a proof stress of 11 tons. These figures must be considered along with a specific gravity of about 1.9. In view of the development of airscrews of adjustable pitch—with the concomitant of a heavy hub—a saving in weight in the blades themselves is naturally of prime interest.

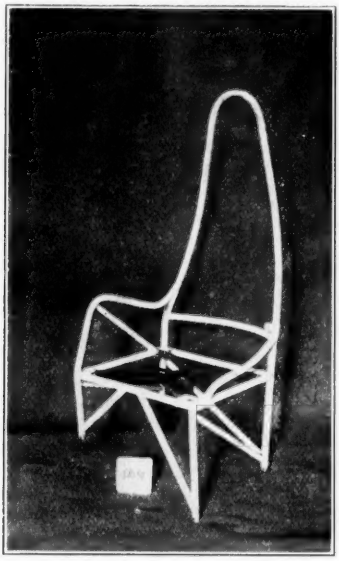


FIG. 5.
Elektron seat frame, welded tubes weight 4.1*lbs.*

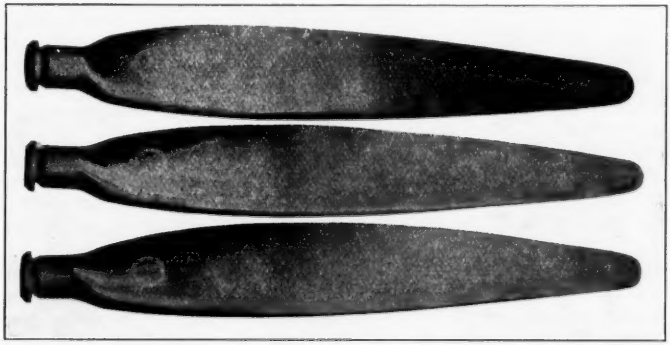


FIG. 6.
***Finished elektron** airscrew blades* (6*ft. long*).

FIG. 7.
Three-bladed elektron airscrew.

FIG. 8.
Four-bladed elektron airscrew.

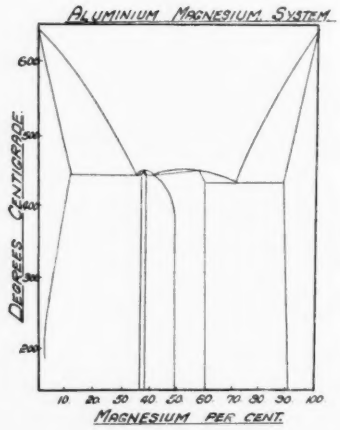


FIG. 9.

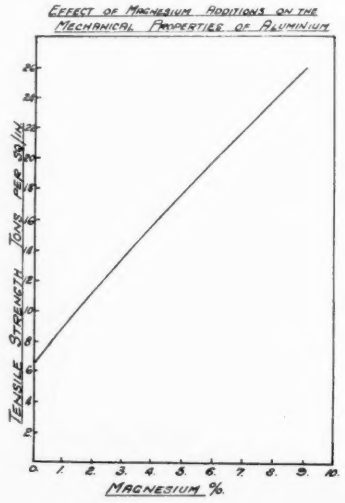

EFFECT OF MAGNESIUM ADDITIONS ON THE MECHANICAL PROPERTIES OF ALUMINIUM
TENSILE STRENGTH TONS PER SQ/IN
0 1 2 3 4 5 6 7 8 9 10
MAGNESIUM %

FIG. 10.

Already the use of magnesium airscrews is very extensive on the continent, particularly in Germany, and the results over the past three years have shown an unqualified success. The development in that country goes on apace because the quantities already in use are of such proportions as to make the production of these blades relatively cheap. More recently, very striking performances are reported on magnesium alloy propeller blades from the United States, where they have been used with great success in conjunction with a hub mechanism which permits adjustability of pitch in flight. Meanwhile, in this country the Bristol Company have made upwards of twenty or thirty airscrews in this material, of the two, three and four-bladed type. It is gathered that their performances up to the present, both in spinning, bench tests and in flight have been entirely satisfactory.

Although the exact weights of the complete airscrews are not available, it may be mentioned that one of these blades, measuring 6 feet from the butt to the tip and 11in. at the widest part, weighs in the finish machined condition about 45lbs., while a blade 5ft. 2in. from butt to tip and 10½in. in the widest part in the finish machined condition weighs about 36lbs. As still stronger alloys are now being developed for airscrews, the prospects are bright. These alloys offer a proof stress of above 14 tons per square inch, against the 11 tons given by those so far employed. Contemporaneously, forging technique has advanced very considerably and to a point where reasonable quantities of these blades can be produced quite economically.

This portion of the subject can apparently be summarised quite simply—mainly by comparing magnesium alloys with those of aluminium. It is clear that as regards the ratio of mechanical strength to specific gravity, the best magnesium alloys when cast are superior to those of aluminium. When wrought the two series are about equal to one another judged on this same basis, but in both the cast and wrought states the magnesium alloys are inferior in elastic modulus. The magnesium alloys of high mechanical strength have the advantage of being weldable in a far greater measure than the aluminium alloys and it is now possible to protect the magnesium alloys against corrosion to an extent that makes them satisfactory for reasonable service.

In view of the difficulty of protecting magnesium and its alloys against corrosion, it would no doubt appear to be rather strange to discover that the most successful means so far discovered of producing an aluminium alloy highly resistant to corrosion is by the addition of suitable proportions of magnesium to the aluminium. There is really no particular reason for surprise, when the matter is considered calmly, but it is very interesting and important to observe the properties of these straightforward binary alloys of aluminium and magnesium.

A glance at the thermal equilibrium diagram for the aluminium-magnesium alloy system given in Fig. 9 suggests that the range of composition within which useful alloys of magnesium with aluminium may be produced is not unlimited, and, broadly speaking, the maximum amount of magnesium which can be present in any commercially practicable metal is about fifteen per cent. Even this figure is really rather a theoretical maximum in so far as wrought metals are concerned, and percentages decidedly lower than this have to be considered as representing the practical limits for working. Upon the mechanical properties, the addition of magnesium to aluminium has an effect almost directly proportional to the percentage of magnesium which is added, and this can be well seen from the test values given in Table XIX.

The figures actually quoted in Table XIX are for the wrought metal in the annealed condition and illustrate very definitely the mechanical possibilities of this series of alloys. From Fig. 10 the close relationship between the magnesium content and the strength is very apparent. The mechanical properties given by this series of alloys are very interesting, but since they can be matched and even well beaten by many other aluminium alloys, they would not be in themselves

of tremendous value were it not for the additional interest provided by the capacity of these alloys to resist corrosion. From such evidence as is available, it seems fairly certain that the capacity for resisting corrosion of these alloys is also a linear function of the magnesium content, provided always that the alloys can be made in such a way that the magnesium is kept in solid solution. In the absence of this qualification, it seems fairly certain that the corrosion-resistance of the material is not greatly increased by the addition of further proportions of magnesium, but is, in fact, increased only in ratio to that proportion of the magnesium which is taken into and kept in solid solution in the aluminium.

TABLE XIX.

EFFECT OF MAGNESIUM ON THE MECHANICAL PROPERTIES OF ALUMINIUM (WROUGHT AND ANNEALED).

Magnesium per cent.	Proof Stress. tons/sq. in.	Maximum Stress. tons/sq. in.	Elongation per cent.
0	2.0	6.20	40.0
1	6.0	9.50	29.0
2	6.45	11.50	25.0
3	6.92	13.60	24.0
4	7.65	15.00	24.0
5	8.30	17.15	22.0
6	9.60	20.00	22.0
7	10.75	22.50	21.0
8	12.20	24.50	21.0
9	13.10	25.80	20.0

A certain amount of doubt exists as to the exact amount of magnesium which can be kept in solid solution in these alloys at room temperatures and therefore exert corrosion resistance, but it appears to be fairly certain that in an alloy containing five per cent. of magnesium, the majority of the magnesium is effective, that with seven per cent. a rather smaller proportion of the magnesium is effective, and that at nine per cent. or more there is very little increase in the effective magnesium content of the metal over that in the seven per cent. alloy.

This position has not been entirely appreciated until relatively recently and probably accounts for the fact that some of the earlier alloys containing seven or nine per cent. of magnesium did not prove to be so consistently resistant to corrosion as would have been expected. Since the true nature of the position has been recognised, it has been possible to give special thermal treatments to the alloys in this group, with the result that their capacity for resisting corrosion has been very considerably extended and the reliability of the material in this respect brought to an entirely satisfactory pitch. That these alloys of aluminium and magnesium are capable of resisting corrosion very effectively and satisfactorily can be seen from the results of actual corrosion tests carried out by observing the effect upon their mechanical properties produced by exposing the metals to a sea-water spray.

In order to make the comparisons, the results are also shown in Tables XX to XXIV of the behaviour under similar circumstances of a variety of aluminium alloys, the nature of which is perhaps well known. The results given in these tables can be approximately summarised as follows:—

TABLE XX.

EFFECT OF CORROSION BY SEA-WATER SPRAY UPON THE MECHANICAL PROPERTIES OF MG7 SHEET.

Days' Exposure.	Proof Stress. tons/sq. in.	Maximum Stress. tons/sq. in.	Elongation per cent.
0	18.20	25.30	13.0
50	18.20	25.40	13.5
100	18.10	25.10	13.0
150	17.95	24.50	12.0
200	18.05	24.10	11.0

TABLE XXI.

EFFECT OF CORROSION BY SEA-WATER SPRAY UPON THE MECHANICAL PROPERTIES OF BIRMABRIGHT.

Days' Exposure.	Proof Stress. tons/sq. in.	Maximum Stress. tons/sq. in.	Elongation per cent.
0	13.20	19.5	12.0
50	13.15	19.5	12.0
100	13.21	19.0	11.0
150	13.00	19.1	10.5
200	12.95	18.7	10.0

TABLE XXII.

EFFECT OF CORROSION BY SEA-WATER SPRAY UPON MECHANICAL PROPERTIES OF DURALUMIN SHEET.

Days' Exposure.	Proof Stress. tons/sq. in.	Maximum Stress. tons/sq. in.	Elongation per cent.
0	17.90	26.60	18.0
50	16.50	26.15	16.0
100	16.20	24.70	12.0
150	16.35	23.10	8.0
200	15.50	22.50	6.5

TABLE XXIII.

EFFECT OF CORROSION BY SEA-WATER SPRAY UPON MECHANICAL PROPERTIES OF RR. ALLOY SHEET.

Days' Exposure.	Proof Stress. tons/sq. in.	Maximum Stress. tons/sq. in.	Elongation per cent.
0	22.5	27.10	11.0
50	20.5	24.25	7.0
100	19.8	22.00	3.5
150	17.5	20.20	2.0
200	14.5	14.7	Nil

TABLE XXIV.

EFFECT OF CORROSION BY SEA-WATER SPRAY UPON MECHANICAL PROPERTIES OF SUPERDURALUMIN SHEET.

Days' Exposure.	Proof Stress. tons/sq. in.	Maximum Stress. tons/sq. in.	Elongation per cent.
0	23.0	29.50	12.0
50	22.0	27.10	8.0
100	21.6	24.20	4.0
150	19.5	22.10	0.5
200	15.2	15.2	Nil

1. The alloys of aluminium that contain appreciable proportions of magnesium, but are free from other elements, are able to resist corrosion more satisfactorily than any other known alloys having aluminium as a basis.
2. Those other alloys that have received but a single heat-treatment and have been aged at room temperatures (such as Duralumin) are the next most resistant to corrosive attacks.
3. The alloys which have received a second heat-treatment, *i.e.*, by precipitation at temperatures between 100 and 200°C. (such as Super-Duralumin and the RR. alloys) are very greatly inferior in their resistance and are the least resistant of all the alloys to corrosion.
4. Amongst the plain aluminium-magnesium alloys containing more than five per cent. of magnesium, there is no noticeable difference in the resistance to corrosion.

Although these test figures show no conspicuous advantage from the corrosion standpoint, due to proportions of magnesium higher than five or six per cent., it must not be overlooked that the higher percentage of magnesium must be present in order to impart the requisite strength to the alloys so that they shall

be mechanically valuable to the aircraft designer, and it is possible to avoid the use of any unduly large amount of cold work in strengthening these alloys if a sufficiency of magnesium is added. To illustrate this point, the figures in Table XXV are worth careful consideration:—

TABLE XXV.

THE MECHANICAL PROPERTIES OF THREE ALLOYS OF ALUMINIUM AND MAGNESIUM.

	Proof Stress. tons/sq. in.	Maximum Stress.	Elongation per cent.
Birmabright	20.50	23.90	3.0
MG7	17.50	24.90	14.0
MG9	12.50	25.40	21.0

These figures show the mechanical properties of three different alloys:—

(*a*) Birmabright,
(*b*) MG7,
(*c*) MG9,

each of which has been given a certain amount of cold work and consequently possesses approximately the same value of maximum stress. To produce this high value of maximum stress in birmabright a great deal of cold work has had to be applied, as can be seen from the low ductility figures possessed by the metal. The MG7 has had to be cold worked very much less to possess the same strength, whilst the MG9 material has not been cold worked at all, as can be judged again by the very high values of ductility possessed by the alloy. It is clearly in this direction that the use of higher proportions of magnesium have their advantage, resulting in high values of maximum stress with a definitely increased ductility in the product and consequently greater facility in working.

A further point that must not, of course, be overlooked in connection with these alloys is that an increase in the magnesium content of the alloys results in a decrease in their density. To the aircraft designer this is a matter of very considerable importance and it is therefore of interest to examine the actual values of specific gravity possessed by a series of these alloys, these being set out in Table XXVI.

TABLE XXVI.

THE SPECIFIC GRAVITY OF ALUMINIUM-MAGNESIUM ALLOYS.

Magnesium, per cent.	Specific Gravity.
0	2.702
2	2.681
4	2.661
6	2.641
8	2.621
10	2.601
12	2.582
14	2.562

Obviously, these alloys of magnesium in aluminium can fill a considerable gap for the aeronautical engineer. They provide a good range of mechanical properties—starting with the alloys quite low in the scale—such as D2 and 4S. Following these in the strength scale comes Birmabright and after this the MG7 and MG9 materials. Naturally, none of these alloys is a perfect material—capable of displacing all others of a similar strength—but they certainly seem to be destined to play a great part in the field of aeronautical engineering in the future.

In conclusion, I should like to express my gratitude to Dr. Walter Schmidt and Mr. E. Player for so kindly providing me with data incorporated in many of the tables in this paper.

Discussion

Mr. W. C. Devereux (Managing Director, High Duty Alloys, Ltd.): It was more than 15 years ago when he first heard Dr. Aitchison read a paper and the subject was valve steels. From the present paper it was fairly evident that Dr. Aitchison was somewhat biassed in favour of magnesium alloys, but for really high power engines these had not been a success altogether and he did not think a designer would feel justified in taking the ultimate stress or the specific tenacity in designing his engine. He had been hoping that Dr. Aitchison would have given some creep stress figures, say, at temperatures of 100 deg. C. or over, which were associated with engine construction, and also some proof stress figures. The paper contained proof stress figures for the cast aluminium alloys but the yield point figures for cast magnesium alloys. In his view the author had mis-stated the true position with regard to magnesium propeller blades. Some beautiful photographs had been shown of such blades and if it was the intention to show that this material could be manipulated in the form of propeller blade forging then the author had succeeded. When these photographs had first been put on the screen he had thought they represented the result of one of Mr. Fedden's fishing days and that the blades were really salmon! The author had referred to them as possibly looking like herrings and he himself was now rather wondering whether they had been shown as a sort of red herring to the entry of magnesium into the aircraft industry! The author had stated that such propeller blades were used in extensive numbers in many countries on the Continent, but he did not think there was a single country that had adopted magnesium propeller blades for service machines. As a matter of fact, he believed that two countries had abandoned them. The conditions in Germany, with their very low power engines, were rather different from the service conditions in other countries, and when the author said that for the past three years the magnesium propeller blade had been an unqualified success—which meant that there had been no troubles from failures—that, of course, was untrue. Quite a number of magnesium propeller blades in this country had been known to fracture, and in America, where many thousands of aluminium alloy blades were in use, he believed he was right in saying that the number of magnesium propeller blades in experimental service could be counted on one's fingers. Mr. Hamilton, of the Hamilton Propeller Blade Co., who had carried out extensive experiments, had expressed the view to me that with engine development as he saw it he did not think it would be possible to produce a magnesium propeller blade, weight for weight, that could compete with aluminium alloys and would be good in service. Since it was true that magnesium propeller blades had failed he felt it was doing harm at the present moment to put them forward as an entirely successful proposition because no doubt our service pilots would say that the men responsible in this country were not keeping on the top line of development—which was not the fact. For instance, quite recently in Germany in one of the large foundries manufacturing elektron castings, a tribute was paid to the work that is being done in this country and it was stated by the principal of that foundry that he owed much in his production of good sand die castings to his association with, and the assistance he had received from, Mr. Player, of Sterling Metals, Ltd.

There was rather a misleading statement in Table XIV in relation to RR.56 as regards the strengths. The author gave the specification figure and the heat-treated figure for this material whereas for duralumin and super duralumin the maximum figures were given, and these related, he rather suspected, to material that had had a certain amount of cold work. In view of these figures he could imagine the Air Ministry representatives present, who had been trying to get the proof stress of these materials put up during the past two years, wondering why the trade had rather been against it. In the case of the RR.56 alloy it was hardly

fair to give only the heat-treated specification figures because it was quite possible to get 24 or 25 tons proof stress with 32 to 34 tons ultimate strength, yet one would not give these figures as characteristic of the alloy. In regard to the strength at temperature it was true that the author said he had given these figures after a quick test, but a quick test was hardly satisfactory and was probably the reason for the discrepancy that occurred between these figures and the figures of other authorities. It would also have added to the value of the paper if the author had given the sizes and shape of the test piece used on the Woehler test, because with the duralumin type of alloy with 4 per cent. copper there was a distinct difference due to variations in shape with the effect of cold work during fatigue testing. He agreed with the author that alloys relying on precipitation treatment were more susceptible to corrosion, but with the improvement in anodic and other treatment this was not so distinctly troublesome particularly in aircraft engine construction with which he himself was mainly concerned. This was borne out by the fact that more than 90 per cent. of the applications in England made use of aluminium alloys of that type and the same applied to many countries on the Continent. The results with the MG.7, MG.9 and alloys of that type had been a little disappointing compared with what was thought possible three or four years ago, due to the difficulty of cold work.

In using magnesium for the crankcases the Isotta Fraschini Company do not seem to have saved any weight over the aluminium crankcase, comparing the weight of their crankcases with the h.p., and then making the comparison between similar h.p. engines and the weight of the crankcases of engines made in this country and in France.

Mr. H. SUTTON (F.R.Ae.S.): The author, being connected with the manufacture of magnesium alloys, had made a considerable contribution to the advancement of them and those who had been trying to use magnesium in aviation and had been considerably helped by the author's work.

He would venture to be mildly critical on one or two points. As regards specific tenacity he was rather worried to see the author give a qualified blessing to that property, but it would have been of great service to designers and constructors if it had been stated what was the ratio of 0.1 per cent. proof stress to density.

With regard to fatigue properties, it was desirable that authors, when quoting results, should mention the form of the material, *i.e.*, the condition of manufacture and whether wrought or cast.

Commenting on Table XV, Mr. Sutton said he would have liked to see more details about the area of the cross-section of the bars and the mode of manufacture and he expressed the hope that the conditions were all comparable for the different materials. The figure of ± 8.9 tons for the Woehler range of wrought elektron appeared to be a little high; the best result he had obtained was ± 7.6 on any section of that material. It might, however, be that the author's recent manufacture had been much improved in that particular respect.

Would the author say what particular proof stress applied to Tables XI and XV; was it 0.1, 0.2 or 0.5 per cent.?

Commenting on corrosion resistance, Mr. Sutton said that the chromate treatment had recently been considerably improved and shortened in time and he hoped in the near future to be able to report some tests which would bear interesting comparison with those given in the paper.

Continuing, Mr. Sutton said there are several disadvantages and difficulties in connection with magnesium alloys which the author had either not touched upon at all or had only done so very lightly. First of all there was the limit of proportionality which was rather low in wrought or cast material. This, in addition to low capacity for deformation at normal temperatures, was rather a serious disability of magnesium alloys. As was mentioned by the author in presenting the paper—but it did not appear in the printed paper—there was no

thoroughly satisfactory alloy at the present time for cold forming. For instance, no rivets were used in magnesium-rich alloys, but he was confident that research would make suitable alloys available in the next 10 or 15 years, if not earlier. Another disadvantage of magnesium alloys was the fact that they were notch sensitive. Dr. Ludwig, of Vienna, had given values of notch sensitivity as follows:—Elektron AZM, 9; duralumin heat treated, 0; yellow brass, 0; structural steel, 21; and in design work great care was necessary to see that parts subjected to alternating stress were free from sharp corners, because stress concentration might be very dangerous in parts made of magnesium alloys. Ludwig's tests had been made on ordinary fatigue samples, round which a notch had been machined and the difference between the fatigue ranges of the unnotched and the notched samples was expressed as a percentage of the fatigue range of those which were tested without a notch. Again, small castings particularly, although superficially sound were sometimes found to be porous to oil and petrol under high pressure, and although he had great admiration for the superficial soundness of magnesium alloy castings generally, trouble was experienced in small ones from the point of view of porosity.

Yet again, there seemed to be some difficulty in getting a casting of magnesium-rich alloy with a high Brinell hardness, a feature which was sometimes required in parts subject to friction.

On the other hand, there were several advantages of magnesium-rich alloys not mentioned or only lightly touched upon by the author, which were well worth special mention on account of their practical value. For instance, there was the increased rigidity obtainable by the use of pieces of considerable bulk in magnesium.

Then there was the advantage of magnesium for use in parts working at high speeds due to the reduced weight; for instance, airscrews. Again, magnesium had the advantage of low modulus of elasticity and a high fatigue limit at the same time, an important feature in material required to damp out vibrations. Magnesium also had marvellously good machining properties and he knew of no other metallic material which came within the same range. It also permitted of greater tolerances on sections owing to the greater dimensions.

Dr. SCHMIDT (German metallurgist to the Company manufacturing Elektron): He said he would like to give some facts which might illustrate where elektron metal consumption in aircraft stands to-day which would, at the same time, bear on the comments of Mr. Devereux. First with regard to the use of magnesium castings for aircraft engines, he said that for instance Isotta Fraschini, in Milano, is making engines for aeroplanes and seaplanes for which all cast parts, with the exception of cylinder blocks and cylinder heads, were made of elektron. When Signor Balbo undertook his flight across the world with his squadron of seaplanes, all the engine crankcases and many other parts were constructed of elektron metal, and it could not be imagined that the Italians would have trusted the success of this flight to elektron metal if those responsible had not been thoroughly satisfied by many thousand motors being built up for important uses with this metal.

Speaking with regard to propellers, Dr. Schmidt said that on the occasion of the International European Flight in 1932 all German aeroplanes used elektron propellers. About twenty German aeroplanes participated in those tests and every one had an elektron propeller. Moreover, just before he started from Germany to attend this meeting there had been a discussion with regard to the preparations for the International European Flight next year, and it is the intention to equip the participating German aeroplanes with elektron propellers. Furthermore, the Deutsche Lufthansa has adopted elektron propellers on the big aeroplane of the Junkers G.38 type. This machine is fitted with four motors each of which has a four-blade airscrew, so that there were 16 elektron blades on the machine. These had been in service last summer and the German company

would not have done that unless they were satisfied that these blades were a success.

Speaking with regard to the general situation concerning propellers, Dr. Schmidt said that magnesium was specially suitable for the larger diameters, although for the small low priced propeller perhaps the interest was not so great. So far as large propellers were concerned, there had been 300 in operation during the past three years and there had only been two failures. One of these elektron propellers broke in England and the other in Germany, and in both cases the fault did not lie primarily with the metal, but with defects in design, which had even been discussed before the tests. However, there had only been these two cases of failure of elektron propellers and if any others had happened he would be extremely pleased to have details, because his company would take all necessary steps to ascertain the reason. In Germany considerable use was made of aluminium magnesium alloys for making the pontoons on seaplanes and he would not be going too far if he said that a very large proportion of such pontoons in Germany are now made in such alloy.

With regard to the fatigue figure of 8.9 tons given in Table XV of the paper, some authors obtained even higher figures because the result depended very much on how the metal was tested. In this connection it was worth noting that a feature of elektron metal was that by first loading lightly and gradually increasing the load the material became, so to speak, familiar with the stress and actually became stronger during the test, and it was in this way that higher figures than 8.9 were sometimes obtained.

Another interesting point was the manner in which tests were made. Mr. Sutton had stated that elektron was susceptible to notch effect, which was true, and small differences in methods of preparing the test pieces gave different figures. The figure 8.9, however, corresponds with the normal fatigue value. For a design in elektron it was necessary to consider this liability to notch effect. He would go so far as to say that elektron in the form of castings was the best to adopt because it enabled two things to be done at the same time, namely, to save weight on the minor stressed parts and increase the factor of safety on the higher stressed parts, the latter being stiffened up in wall thickness wherever needed.

As to the difficulty caused by water in tetra-ethyl-lead-doped fuels, this has been overcome by putting into the magnesium fuel tanks a small bag containing potassium fluoride, which was dissolved by any moisture that might be present and so counteracted any possible effects in the way of corrosion.

The main use in aircraft of wrought magnesium alloys was for cowlings, tanks and seats. Nearly every newer German aeroplane had elektron seats whilst the body of the cars and also the tanks were made of the same material.

Incidentally, Dr. Schmidt mentioned that the new long distance aeroplanes run by the Dutch Company—K.L.M.—from Amsterdam to Batavia all had cowlings of elektron and some had tanks of that material. A careful study had also been made of vital supporting parts and there had actually been made in Germany a sporting aeroplane wholly in elektron. The idea had been to test that against another aeroplane made wholly of duralumin, and in that particular case they had been careful not to make the elektron aeroplane more than about 5 per cent. lighter than the duralumin one. Whilst that might at first seem ridiculous, at the time the test was contemplated it was felt there was still a great deal to learn as to stresses, and therefore a limit of 5 per cent. saving in weight was imposed. Although a start was made by compiling very careful comparative data, the test was not completed because the duralumin aeroplane had an accident. The elektron aeroplane, however, had now been in service for three years and very careful inspections were carried out every half year. The machine had given very good service notwithstanding that many tests had been carried out

upon it of a severe nature, and as a result it was hoped that some progress would be made in the near future in the use of magnesium for heavily stressed aircraft.

Dr. SCHMIDT (*communicated*): With regard to the reply which Dr. Aitchison made at the end of his lecture, the writer has since ascertained that his company had not delivered any propellers to Messrs. Letov, Prague, with whom they were in touch at one time. The statements made by Mr. Devereux, that an elektron propeller of this firm broke, thus loses its point, neither is anything known of the breakage of a propeller at Fiat. On the contrary, they have had reports from Messrs. Fiat, as a result of the tests of their propellers, recognising their worth.

Mr. P. PRITCHARD: As a prejudiced party on the subject of magnesium alloys he had not intended saying anything in the discussion, but perhaps he might supplement what the author had said with regard to castings. As a foundryman he had always held that good castings of inferior material were to be preferred to unsound castings of what might be regarded as a good material, but he definitely made the statement on behalf of magnesium that, taken on the whole, magnesium castings were much more to be relied upon for soundness than aluminium castings. He made that statement having had some experience in the manufacture of both classes of casting.

The only other point he wished to mention was the comparison of tensile strengths in elektron between the orthodox figures as revealed by the test bars and the actual figures in the casting itself. There again he believed magnesium had a decided advantage over the ordinary aluminium alloys in as much as it was usually far easier to obtain a higher percentage of the figures given by the test bar in the actual casting in magnesium than it was with aluminium alloys. In connection with aluminium alloys, he asked the author's opinion as to the value of the cold working properties of the higher magnesium alloys compared with the lower ones.

Mr. W. C. DEVEREUX: Commenting on what Dr. Schmidt had said regarding magnesium alloy propeller blade failures, he said he had seen two broken magnesium alloy propeller blades at the Military Institute at Prague. Referring to the remarks by Dr. Schmidt as to the effect on magnesium test pieces tested by the method of gradually increasing the load during test, he said that was referred to over here as "old soldiering"!

By using magnesium for the crankcases the Isotta Fraschini Company do not seem to have saved any weight over the aluminium crankcase, comparing the weight of their crankcases with the h.p., and then making the comparison between similar h.p. engines and the weight of the crankcases of engines made in this country and in France.

Dr. A. P. THURSTON (F.R.Ae.S.): Speaking as a possible user, he asked if the author would give the specific heat, the coefficient of linear expansion, the heat conductivity, the strength in bending and compression, and the behaviour under alternating stress of the more common of the alloys mentioned in the paper.

Mr. G. A. ANDERSON (British Aluminium Company) (*communicated*): There are one or two points in the text of the paper to which he would like to call Dr. Aitchison's attention.

Firstly, if he will refer to Table VII he will see that the heading reads "The Influence of Manganese Additions upon the Mechanical Properties of Manganese"; this last word should, he presumed, be "Magnesium." Secondly, Table XIV is stated to show the properties of wrought alloys in the extruded condition. It might be better if the table were headed "Extruded and Heat Treated," since the properties shown would not be obtained if the alloys had been merely extruded with no subsequent treatment. In this connection it would be interesting to know whether Table XII refers to magnesium alloys which have been merely extruded, or extruded and given some after treatment.

In his lecture, he thought Dr. Aitchison rather underestimated the importance of corrosion as a factor in metal aircraft. In order to use the material in the most economical way aircraft designers are forced to employ members of rather intricate cross-section and to employ many small members joined together rather than fewer and larger spars and ribs. This means that there are many positions which would be difficult to protect adequately by painting and many contact surfaces between which moisture can be drawn by capillary action. Therefore, until a process for the surface protection of magnesium alloys is discovered which is as perfect as the anodic oxidisation process for aluminium alloys, he thought the former materials were at a great disadvantage so far as aircraft construction was concerned.

Table XVI, giving the comparative strength of magnesium and aluminium alloys at high temperatures, is extremely interesting. The serious loss of strength of the magnesium alloys when the temperature is raised to, say, 250°C. is a most important factor when considering their adoption for pistons and connecting rods. The temperature of the crown of a piston will frequently reach 250°C., while measurements carried out on the temperature of a big end bearing in a high performance motor car engine have shown the temperature at this point may rise to over 200°C. If the magnesium alloys are to be used under these conditions the bulk of material would have to be increased to give adequate strength to such an extent that no advantage would be gained from the lower specific gravity of the magnesium alloys compared with those of aluminium. It would also be of interest to know whether any information is available as to the frictional qualities of the magnesium alloys at temperatures up to 200°C. Aluminium alloy connecting rods are being successfully run to-day without any big end bearing in the usual sense of the term, *i.e.*, the material of the rod itself is used to form the bearing. It would be interesting to know whether Dr. Aitchison considers such a procedure possible with the magnesium alloys.

He thought Dr. Aitchison was perhaps rather over emphatic on the difficulties of welding aluminium alloys. A certain amount of practice is needed before a welder, who is accustomed to dealing with steel, can make satisfactory welds in aluminium and its alloys, but there is no real difficulty in the process and there are many welded structures which are to-day doing service commercially, such as aircraft petrol tanks and road tankers for transporting a number of liquids in bulk. The stresses on these tankers are quite high, but the welded construction has been found to stand up admirably. While welding in the usual way does, admittedly, let down the strength of heat-treated alloys, he thought the spot welding process bids fair to overcome this difficulty. By accurate control of current and time the area affected by the weld can be kept very small and tests have shown that spot welded joints show a strength rather greater than a riveted joint of the same area. This system, of course, has the disadvantage that it cannot be used to make a watertight joint.

The notch sensitivity of the magnesium alloys, mentioned by Mr. Sutton, is a factor which would have to be allowed for very carefully in design. It would also be interesting to know whether the low surface hardness of the magnesium alloys, coupled with this sensitivity, has caused any failures in propellers at score marks caused by flying, say, through a sand storm, or by stones, dirt, etc., thrown against the propeller when on the ground. It certainly seems that this type of failure is a possibility and that the surface of a magnesium alloy blade must be kept in good condition if it is to be avoided.

Mr. W. O. MANNING (F.R.Ae.S.) (*contributed*): He noticed during the discussion on this paper that considerable stress was laid by certain speakers on certain failures of duralumin and magnesium propellers which have occurred in flight. Without knowing the circumstances in each case it seems to be hopeless to attempt to draw any useful conclusions from such cases.

The principal materials out of which propellers have been made are wood, steel, aluminium alloys and magnesium alloys, and failures have occurred in propellers made in each of these materials. He had seen a number himself, and would suggest that in every case the failure is not attributable to the material itself, but either to some defect in design, to the existence of notches, or to the material not being in a satisfactory condition, due possibly to incorrect heat treatment or some similar cause. In certain cases the failure may have been due to defective upkeep.

He noticed that in a recent paper on engines by Mr. Fedden, he states that he has found magnesium alloys to behave very much better than aluminium alloys when used as bearing metals. It is known that many aluminium alloys are fairly satisfactory in this respect, and if magnesium alloys are even better some information would be of much interest.

He would ask if Dr. Aitchison has any data on this aspect of the subject which he could publish, including, if possible, some information on composition and a comparison with the generally used types of bearing metal.

Mr. H. C. HALL (Rolls-Royce, Limited) (*communicated*): One might conclude that magnesium alloys are more than promising rivals of aluminium alloys even when employed for high duty service, this in spite of their low elastic modulus.

With respect to corrosion, this will probably prove unimportant since surface treatments promise to give adequate protection.

Considering castings in magnesium alloy, these are stated to be better than produced in the past. It appears, however, that recent castings of excellent external appearance still contain oxide inclusions which are practically impossible to discover by external inspection.

Such flaws may be relatively unimportant in castings not used for aeronautical purposes, but are dangerous under high duty service, particularly under warm conditions.

When considering lightness, it must be borne in mind that thin RR.50 castings (.100in. sectional thickness), are a practical proposition and safer than magnesium castings even though the latter be 50 per cent. thicker, *i.e.*, of greater weight in aluminium alloy.

Table VIII is an excellent example of extreme sensitiveness. The extraordinary effect of 0.04 per cent. silicon on magnesium is difficult to explain. Is it due to a critical dispersion of Mg_2Si, which effects recrystallisation on working? The effect on castings is much less marked, confirming that it is something to do with working.

In connection with Table IX, he concluded that the aluminium alloy bars were cast in the standard A.I.D. chill, on the other hand, it is difficult to cast magnesium alloys in this design of mould without a very large proportion of wasters; in fact, he believed it had been found to be practically impossible.

Under these circumstances he would like to know how the magnesium alloy bars were cast. Was it in the horizontal trough mould? If so, the aluminium alloys mould also would give better results if cast in the same way.

The satisfactory comparisons of the alloys may also be affected by the relative physical condition of the aluminium alloys; for instance, the chill cast 2L.8 has apparently not been stabilised by sufficient ageing, since it should be then about 84 Brinell, not 68-73 as given in the table.

Table XIV.—These figures do not appear to be a fair comparison since the minimum specification acceptance figures are quoted for RR.56 and these are generally easily exceeded. The figures quoted for super duralumin would appear to be exceptional and it is quite probable that the specific tenacity figures might be reversed.

Table XVI.—From the practical standpoint and for useful comparison long soaking at temperature has been proved essential. If the various alloys had

been soaked even for half-an-hour at the higher temperatures quite different results would have been obtained.

The magnesium alloys would then have become much softer. The effect on the aluminium alloys being much less. After half-an-hour at 300°C. RR.59 would give about 14 tons as compared with 11.8 tons for " Y " alloy and 12.5 tons for RR.56.

Magnesium alloys under creep test, even at a temperature as low as 100°C., give a markedly lower value than at ordinary temperatures, whereas aluminium alloys for high duty are not materially affected in this respect at 160°C. This also applies to cast alloys.

The heat treatment, with a view to getting an improved corrosion resistance, appears to be in the nature of an annealing. Similar treatments have been found advantageous in the case of aluminium alloys. In the latter case a combination of an ageing treatment with a chemical one has resulted in a greatly increased resistance to saline corrosion.

Considering Tables XX to XXIV, it would be illuminating if the section of sheet or bar were indicated, since this has a considerable effect on the relative loss of strength and ductility.

The method of ageing in the case of super duralumin and RR.56 would also be interesting since, as indicated above, the corrosion resistance is much influenced by this factor.

If RR.56 had been air aged only the tensile strength and ductility would be quite equal to duralumin both on commencing the test and also after 200 days.

The corrosion product would have been less, however, owing to the lower percentage of copper.

Mr. G. W. LACEY (*communicated*): The author had not given fatigue values for the aluminium-magnesium alloys, and especially the relationship between fatigue values and ultimate stress which, at any rate for the lower magnesium content alloys such as Birmabright, was equivalent to 50 per cent. of the ultimate tensile stress. That ratio was much higher than was achieved with any other high tensile aluminium alloy. It would be interesting to know whether the same ratio or a similar ratio was maintained in alloys containing from 5 to 10 per cent. of magnesium.

Dr. Aitchison has not referred to the fact that the aluminium-magnesium alloys are also casting alloys and the impression might therefore be gained that the aluminium-magnesium combination (with aluminium as the base) is useful only in the wrought state. Good casting alloys are obtained, particularly about the range of composition of " Birmabright," giving very satisfactory mechanical properties, and Birmabright castings have been employed for a number of years in various applications, especially in marine work, for which resistance to corrosive action of the highest possible order is demanded.

REPLY TO DISCUSSION

Anybody who gave a lecture or read a paper was supposed to be " bulling " his subject, and consequently it was quite open to anybody else to carry out a " bear " raid. Perhaps it was just as well that things occurred thus, so that the " bulls " and " bears " tended to equalise, as otherwise the innocent investor might be led seriously astray and possibly be led more into the cart by the " bear " than the " bull."

Referring to Mr. Devereux's remarks, he said that he was not sure he quite understood some of them. One complaint, however, was that in the paper, proof stress values were not given.

Mr. DEVEREUX: For sand castings.

The AUTHOR said that so far as sand castings were concerned, he pleaded guilty, but that he would insert the figures into the final reply to the discussion

(these are appended to Table X). Nevertheless, he had been wondering somewhat as to the extent of his fault, since Mr. Sutton had taken him to task for not stating what criterion had been used for the proof stress. Wherever proof stress figures were quoted in the paper, they were 0.1 per cent. proof stress. Indeed, he had imagined that it was nowadays unnecessary to tell the aeronautical industry that proof stress figures should always be quoted on a 0.1 per cent. basis of extension.

The author had also been taken to task by Mr. Devereux with regard to the fatigue values and the mode of determination. Mr. Devereux might describe certain methods of making the tests as " old soldiering " if he wished, but he must not accuse the author of adopting this practice. Dr. Schmidt had not prepared the paper and in his contribution was only describing a method which *might* be adopted with any metals in order to procure higher figures, if such a practice appealed to the investigator. Because Dr. Schmidt described this possible method of carrying out tests and which might be described as " old soldiering " (in Mr. Devereux's words), there were no grounds whatever for assuming that the test figures quoted in the paper were obtained by this method. The values given in the paper were, in the opinion of the author, not merely accurate but capable of withstanding very careful scrutiny. The author also stated that he would provide in the printed reply a drawing of the actual Woehler test piece that was used in making these investigations (this is shown in Fig. 11). The number of reversals is actually quoted in the headings of the table, namely, 20,000,000.

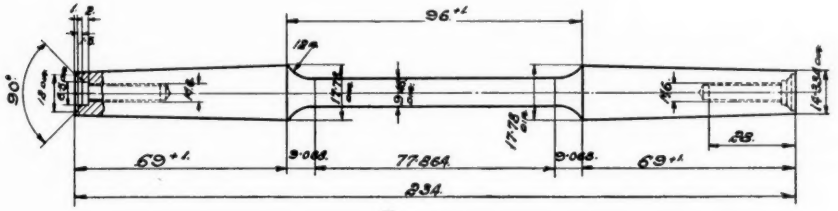


FIG. 11.

This seemed to dispose of two of the " red herrings " which had been drawn across the track of the discussion, and it seemed probable that Dr. Schmidt in his contribution to this discussion had gone a long way towards disposing of the other one about the behaviour of magnesium propellers. Possibly Mr. Devereux was right in regard to the use of the word " unqualified," as this word is very sweeping, and if the statements made by Mr. Devereux were found to be true the author promised to amend the paper by deleting this word " unqualified." (A further contribution by Dr. Schmidt and additional investigation of the matter shows that there are no grounds for deleting the word " unqualified " from the paper.) The author was very much obliged indeed to Dr. Schmidt for the exceedingly valuable information which he gave regarding the performance of propellers. The author's view of the matter was probably formed as a result of the reports he had received from the firms to whom he had sold magnesium alloy propellers, and these reports were definitely to the effect that the propellers had achieved entire success.

Mr. DEVEREUX: In service?

The AUTHOR: Yes, definitely in service—quite a lot of them, I am pleased to say.

With regard to Mr. Devereux's remarks respecting Table XIV, namely, that only the specification value for RR.56 had been inserted, the author must agree that this was so, but he must definitely protest against the suggestion

that the other figures in the table had been obtained from materials which probably had been cold-worked. In actual fact, there was no " probably " about it; the materials in question had not been cold-worked at all and the maximum stress of 26½ tons quoted for extruded and heat-treated Duralumin bar was ridiculously low.

Mr. DEVEREUX: But the super duralumin quoted is a specification figure and not an actual figure.

The AUTHOR: There is no specification figure for super duralumin, but in order to make everything perfectly clear he would alter the figures in Table XIV and insert specification figures where they exist. He was most anxious to establish the fact, however, that the results obtained on Duralumin, " Y " alloy and Super Duralumin were not in any way dependent upon cold work. All the materials were straight quenched and heat-treated specimens.

Commenting on the remarks by Mr. Sutton, the author expressed the hope that in the paper he had not stressed the " specific tenacity " too much. If, however, this basis was not employed for comparison, the question arose as to what better criterion than " specific tenacity " could be employed. The same difficulties that Mr. Sutton described arose if proof stress was adopted in place of maximum stress, and the author would be most thankful and delighted if somebody could devise a really satisfactory basis for the comparison of various materials which differed markedly in specific gravity. Up to the present, no such criterion has been established. The author had already mentioned that the proof stress values were obtained on a 0.1 per cent. basis, but he wished also to emphasise that the fatigue values quoted in Table XV were carried out upon a properly comparable basis. These were not isolated results collected from one place or another, but were all carried out in similar ways and under similar conditions.

Continuing, the author thanked Mr. Sutton for mentioning a number of things which had been omitted from the paper and proceeded to refer to Dr. Schmidt's remarks, for which he was very grateful. He said that he almost felt that it might have been preferable for the Society if his position and Dr. Schmidt's had been reversed. If, however, Dr. Schmidt had read a paper on this subject, the author felt sure that he would not have been able to make such a valuable contribution to the discussion of Dr. Schmidt's paper as Dr. Schmidt had contributed to his. He had already pointed out the possible interpretation of Dr. Schmidt's remarks about fatigue tests and would once again assure the meeting that the figures given in the meeting had not been obtained by " running up."

In reference to Dr. Thurston's questions, the author said that he would answer them in writing and would include a value for the coefficient of expansion.

The author stated that the question raised by Mr. Pritchard had really been answered in advance in Table XXV. He believed that Mr. Pritchard's question had reference to the fact that as the strength of the material increased through the addition of magnesium, its ductility necessarily fell off, and the capacity for receiving cold work definitely fell. If Mr. Pritchard meant to ask whether Birmabright would work more easily than MG.7, the answer was obviously " yes." Similarly, if some of the magnesium was removed from Birmabright, the material would work still more easily. The figures in the paper showed that, speaking generally, the ease of working of the alloys in the magnesium-aluminium series was inversely proportional to the maximum stress.

Before replying to the written communications, for which the author would like to express his gratitude, the figures asked for by Dr. Thurston may be quoted. The values vary slightly for different magnesium alloys, but no doubt Dr. Thurston would be satisfied with those for a typical alloy, such as " Elektron AZM."

Specific heat (20°C.)	0.24
Thermal conductivity (C.G.S. units at 18°C.)	0.32
Coefficient of linear expansion :—	
20°-100°C.	0.000024
20°-150°C.	0.0000247 (average)
20°-200°C.	0.0000254 (average)

The yield point in compression of this alloy is 8.0 tons per square inch and the behaviour of the material in fatigue is given in Table XV.

The author is obliged to Mr. Anderson for pointing out a typing error in Table VII. For Table XIV the author has corrected the heading to make it perfectly clear that the materials referred to in Table XII have not been heat treated at all, but simply extruded.

The author has read with interest the remarks which Mr. Anderson has made respecting corrosion and high temperature values of mechanical properties. The point that is mentioned regarding the use of magnesium alloys as bearings is dealt with in the reply to Mr. Manning. The author is not conscious in any way of having laid any particular emphasis upon difficulties experienced in the welding of aluminium alloys. He thinks, however, that it is well known that the heat-treatable aluminium alloys are definitely difficult to weld and thinks Mr. Anderson would agree with him that this particular operation is very rarely indeed applied to such materials. The non-heat-treated aluminium alloys, of course, can be welded quite simply. In regard to the point raised as to the sensitivity of the surface of parts made in magnesium alloys, the suggested troubles on propellers mentioned by Mr. Anderson had not arisen.

Mr. Manning raises a very interesting question as to the behaviour of magnesium alloys when used as bearings. The position of the magnesium alloys in this respect is very similar to that of the aluminium alloys, namely, that the alloys of either type can be used successfully as bearings, provided that they are running against very hard steel shafts. Case-hardened steel shafts with adequate lubrication perform quite satisfactorily when running in aluminium alloy bearings. With elektron, complete success has been obtained when the shafts have been nitrided and polished. Granted full hardness in the shaft and an adequately satisfactory lubrication system, bearings made in elektron have proved consistently to be satisfactory. If conditions, however, are not as described, the material does not function reliably as a bearing.

The author is very grateful for the interesting contribution from Mr. Hall, some of whose points have been dealt with in the replies to other contributors to the discussion. The figures in Table VIII, referring to the effect of silicon, are, perhaps, not so striking as Mr. Hall would have been led to believe by the paper. Unfortunately, an error has crept into the manuscript and the figures for the material free from silicon in the advance proof were not correct. These have been deleted in the final copy and apologies are due to Mr. Hall.

With regard to the point raised as to the way in which the test bars for the aluminium castings and the magnesium castings were prepared, it would be unfair to attempt to cast both types of alloy in the same way. The technique of casting aluminium alloys and magnesium alloys are distinctly different, and the only way to secure a sound comparison is by casting each type of alloy in accordance with the technique that has been found to be most appropriate for it. This practice has been carried out in the preparation of the test specimens which provided the results given in the paper. With regard to the figures given in Table XIV, Mr. Hall's points have been mostly met above, but the author would once again state that the figure given for Super Duralumin is not at all exceptional, unless it be regarded as exceptionally low. In respect to the figures in Table XVI, the results have been secured in a straightforward way, and are therefore strictly comparable. The author has not made tests on RR.59, but the RR.56

material can be taken as typical of this class of alloys requiring a dual heat treatment.

With reference to Tables XX to XXIV, all the test results were obtained upon 18-gauge rolled sheets. The heat treatments given to Super Duralumin involved quenching from 490°C. followed by P.H.T. for twelve hours at 165°C. The RR.56 material was quenched from 520°C. and given P.H.T. for twelve hours at 175°C. The Duralumin was quenched from 490°C. and aged at room temperatures.

The author is not able to agree entirely with Mr. Hall regarding the behaviour of RR.56 when heat-treated in the same way as Duralumin. When given such heat treatment the mechanical properties are not quite equal to those of Duralumin and the corrosion resistance, although it is of the same order as that of Duralumin, is not quite so good. It is, of course, very much better in this condition than when the metal has been subjected to P.H.T.

The author is obliged to Mr. Lacey for pointing out the importance of the aluminium-magnesium alloys in the form of castings and regrets that the impression might have been created in the paper that this aspect of these alloys was being undervalued. The fatigue value of the aluminium-magnesium alloy containing 6½ per cent. of magnesium is about ±9 tons per square inch, when the maximum stress is 22 tons per square inch. The author is very interested in Mr. Lacey's figures to the effect that the fatigue value of Birmabright is ±50 per cent. of the maximum stress. This is the first case that has ever been encountered by the author of an aluminium alloy having a fatigue value greater than ±40 per cent. of the maximum stress.

THE CORROSION AND PROTECTION OF MAGNESIUM AND ITS LIGHT ALLOYS *

BY

GUY D. BENGOUGH, D.Sc., and L. WHITBY, M.Sc., A.I.C.

The chemist regards magnesium as a highly reactive metal for such reasons as the inflammability of its powder or foil in air, its active displacement of hydrogen gas from many aqueous chloride solutions and its position near the reactive end of the electrode-potential series. All these suggest that the metal would be unsuitable for constructional engineering. Yet engineers use alloys, rich in magnesium, up to 98 per cent. of the metal, for an increasing number of services, although the alloying elements do not, as a rule, greatly cut down, and may even increase, the corrosion rate. Their industrial use is possible because the liability to corrode, reckoned over a reasonably prolonged period, is not a definite property of a metal such as conductivity which is subject only to relatively small changes with alteration of environment, but is highly specific to metal-liquid and metal-gas systems. Moreover, these systems may undergo important changes with time owing to the intervention of films of corrosion products, and the rate of attack may be governed by the physical characteristics of these films which will vary with the adjacent liquid and gases. Thus in stagnant caustic alkalies magnesium may be reckoned as almost incorrodible because of the intervention of a film of hydroxide of the self-healing type which, in these conditions, is highly impervious to magnesium ions; but in the presence of alkali chlorides the corrosion product is physically different and rapid corrosion occurs. Many dilute acids attack magnesium rapidly but hydrofluoric acid scarcely at all, no doubt owing to the formation of a protective film of fluoride.

Generally, it is not yet possible to predict the exact conditions in which obstructive films of corrosion product will be formed, though it may be suggested that when anion discharge takes place on a metal before its ions enter solution and these anions form an insoluble compound, then a protective film will be formed. One of us has developed this view in detail for magnesium in a paper published elsewhere (13).

Deposits of the products of corrosion are usually either protective or indifferent, but cases are known in which magnesium hydroxide films actually stimulate the rate of corrosion.

Though corrosion rates are usually determined mainly by factors in the environment, yet they may be affected, to a limited extent, by the amount and nature of metallic impurities, even when these are present in minute amounts, for example, 0.01 per cent. of iron in highly purified magnesium; some of the non-metallic impurities, particularly oxides, silicides and nitrides, have little or no effect (1, 8).

Since a principal use of magnesium alloys is for aircraft and motor parts which are exposed to the atmosphere, either in the presence or absence of liquid fuels and lubricating oils, this gives a convenient division of the subject. We

* Paper read before the Institution of Chemical Engineers, December 8th, 1933, and reprinted by special permission of the Institution.

have little knowledge of the effect of fuels and oils, and the literature is scanty; probably much information is hidden in the archives of engineers from whom we should welcome communications. Our own work has dealt mainly with the effects of the atmosphere, usually reinforced with sea-water spray.

Atmospheric Corrosion of Magnesium

Dry air at laboratory temperatures has little or no action on massive magnesium, but the rate of attack slowly increases as humidity rises to about 90 per cent. of saturation when a rapid increase occurs. Magnesium hydroxide is first formed and adheres to the metal, but this layer is granular and does not at once form a protective film. This may seem surprising when it is remembered that corrosion is rapidly stifled in both distilled water and caustic alkalies; the explanation may be that atmospheric action is largely a direct attack by water vapour and not electro-chemical, and probably gives rise to a physically different corrosion product.

The course of the reaction in a relatively pure indoor atmosphere free from combustion products has been followed and curves drawn in which weight increment and relative humidities are plotted against time (3). At first, every increase of humidity above a critical amount increases the attack which, however, soon dies down again. After a time, increase of humidity loses its effect and the weight remains nearly constant. The explanation seems to be that any pores which exist in the original layer of relatively compact hydroxide are gradually closed by the formation of bulky insoluble carbonate. This secondary reaction between the carbon dioxide in the atmosphere and hydroxide also has a critical humidity and is most active between 75 and 90 per cent. of saturation. Hydrated sulphate is also formed, largely as nodules standing up on a granular background of hydroxide. The composition of the corrosion product is given in Table I; it contains magnesium hydroxide, carbonate and sulphate, probably as basic carbonate and hydrated sulphate of types which vary with conditions of formation.

TABLE I.

Composition of Corrosion Products from Magnesium Exposed to an Indoor Atmosphere.

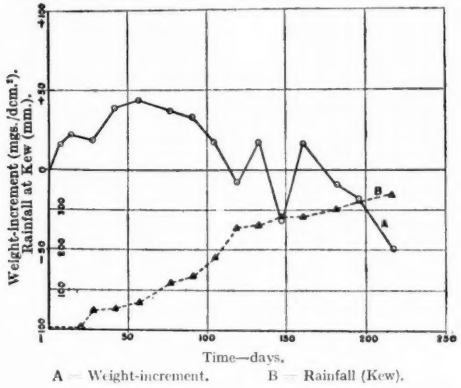
Composition.	Time of exposure in days. 412.	300.
$MgCO_3$	46.5	46.6
$MgSO_4$	9.8	9.7
$Mg(OH)_2$	16.3	15.5
H_2O	27.4	28.2

Curves for a specimen exposed to rain, etc., out of doors at Teddington are shown in Fig. 1 (3); curve A represents weight increment with time; B, rainfall. The film thickness, shown by weight, increases in the dry, initial and later periods, but loss of weight occurs in wet periods owing, no doubt, to the selective removal of soluble constituents, particularly sulphates. These losses are greater in the later stages of attack and this suggests that the formation of soluble material is not the result of primary action. This is the formation of hydroxide, which is afterwards converted into carbonate and then to sulphate, particularly in rainy periods; the rain also washes out the sulphate previously formed so that intermittent formation and removal of film constituents occur. Small glittering crystals gradually appear in the film after a period of rain, which are probably septahydrated magnesium sulphate. The composition of the product is shown in Table II.

TABLE II.

COMPOSITION OF CORROSION PRODUCT FROM MAGNESIUM EXPOSED TO AN OUTDOOR ATMOSPHERE FOR 217 DAYS.

	%
$MgCO_3 \cdot 3H_2O$	61.5
$MgSO_4 \cdot 7H_2O$	26.7
$Mg(OH)_2$	6.4
Carbonaceous matter	2.5
Siliceous matter	Nil
$Fe_2O_3 + Al_2O_3$	2.9



A — Weight-increment. B — Rainfall (Kew).

FIG. 1.

Weight-increment/time curves for magnesium exposed to outdoor atmosphere and correlation with rainfall.

(*By permission of the Faraday Society.*)

A particularly interesting feature of this work is that it shows no permanently protective film is formed on magnesium by exposure to an outdoor atmosphere; even in dry periods a slow increase of weight occurs which is generally followed by a decrease in rainy periods.

TABLE III.

COMPOSITIONS OF ALLOYS USED.

Alloy.	Air Ministry Specification (D.T.D.).	Al.	Zn.	Si.	Mn.	Mg.
British Maximum 66 rolled sheet	120	5	—	—	0.75	94.25
Elektron AZM rolled sheet	125	6.15—6.45	0.8—1.2	0—0.2	0.2—0.5	92.5
Elektron AM 503 rolled sheet	118	—	—	0—0.3	1.3—1.7	98.0
Elektron V1 extruded rod	129	9.5—11.5	0—0.6	0—0.3	0.2—0.5	88.0
Elektron AZG sand castings	59	5.75—6.25	2.75—3.25	0—0.3	0.2—0.5	90.5

NOTE.—Compositions are those given by the makers.

Some outdoor tests on rolled sheets 5 cm. × 5 cm. by 14 SWG of AZM and BM66, having compositions shown in Table III, have been carried out in the

Teddington atmosphere for periods of nearly three years. Although time corrosion curves are not available, the action appears to be similar to but slower than that on magnesium. Losses of weight at the end of this period for bare, chemically treated, and painted specimens are given in Table IV, and Figs. 2 to 5 illustrate some of these specimens. Slight pitting has occurred on all of them, though the chemically treated specimens of BM66, which were dark blue or black, appeared to be quite unattacked before removal of the dark film. This was quite decorative and was produced by 3 hours' immersion in a bath containing 0.5 per cent. sodium persulphate, 1.0 per cent. sodium dichromate and 2 ccs. of 2N-nitric acid per litre of water, which was heated to 80°C. The paint consisted of an aluminium pigment in a bitumen-base medium, but was unsatisfactory as it cracked and developed small holes. Selenium coats were found to be useless.

TABLE IV.

Losses of Weight of Magnesium-Base Alloys after Exposure to Weathering for 2 Years 10 Months.

Treatment.	Losses of weight in gr. B.M. Alloy 66.	Elektron alloy A.Z.M.
Untreated	0.39, 0.40	0.37, 0.39
Chemically coated	0.39, 0.40	0.37, 0.36
Painted	0.28, 0.29	0.36, 0.36
Painted over chemical coating	0.33, 0.35	0.34, 0.33

Another series of tests on sheets of AZM and extruded bars of VI was carried out for a year under three conditions, namely, outdoors, in a kitchen, to test the effects of steam and combustion products, and in the relatively dry atmosphere of a laboratory dark room, which was never below dewpoint and

TABLE V.

Protective Effect of Lanoline against the Atmosphere. Time of Exposure 12 Months.

Alloy.	Treatment.	Atmosphere.	Losses of weight in gr.
VI ...	None	Outdoor	0.11, 0.15
VI ...	Lanoline	,,	0.05, 0.04
AZM ...	None	,,	0.14, 0.14
AZM ...	Lanoline	,,	0.04, 0.04
VI ...	None	Kitchen	0.06, 0.07
VI ...	Lanoline	,,	0.01, 0.01
AZM ...	None	,,	0.06, 0.06
AZM ...	Lanoline	,,	0.01, 0.00
VI ...	None	"Dark room"	0.03, 0.03
VI ...	Lanoline	,,	0.00, 0.00
AZM ...	None	,,	0.02, 0.02
AZM ...	Lanoline	,,	0.00, 0.00

was free from acid and combustion fumes. The results shown in Table V indicate that the outdoor atmosphere was the most aggressive and the dark room the least. Selenium coats were again useless, but lanoline reduced the attack outdoors to about one-third, and practically prevented it altogether in the other conditions. The lanoline coat was thin enough to be unnoticeable, and since it would be cheap it might be used for storage purposes.

The presence of sea-water spray in the atmosphere greatly increases corrosion; quite new factors come into play, since the alloys may be wetted with an

aggressive chloride-bearing electrolyte. In our tests alloys are suspended by wires out of doors and sprayed three times daily with natural sea water; the bottoms of the specimens and the surfaces surrounding the suspension holes remain wet for varying, but considerable, proportions of the test-period. These parts are the most attacked, no doubt by electrochemical action.

The corrosion of many industrial metals such as zinc, iron and steel, immersed in salt solutions, is made up of two distinct types of attack, one of

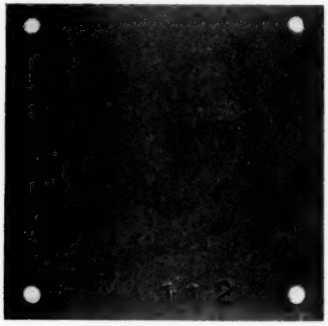


FIG. 2.
AZM alloy, after outdoor exposure for 2 years 10 months.

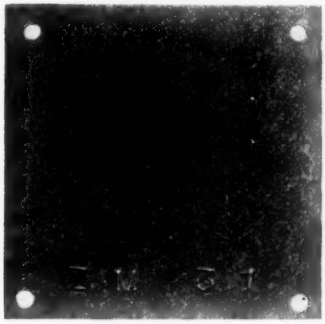


FIG. 3.
As Fig. 2, but chemically coated.

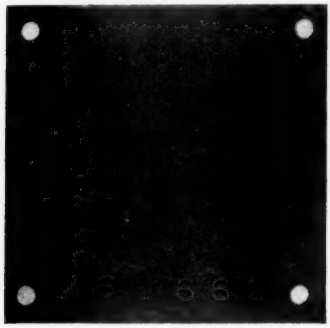


FIG. 4.
As Fig. 2, but British maximum 66 alloy.

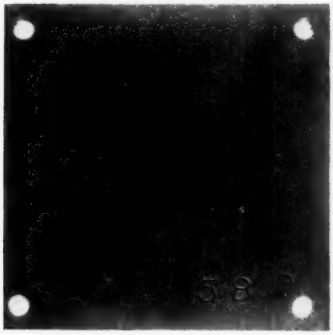


FIG. 5.
As Fig. 4, but chemically coated.

which results in the formation of hydrogen gas, and the other of water owing to the depolarisation of hydrogen by dissolved oxygen. The latter action often corresponds to 90 per cent. or more of the total attack, and therefore the rate of access of oxygen is an important factor controlling the corrosion. The relations of the two types of attack have been studied at Teddington for different metals, and magnesium has been found to represent a case in which the oxygen type is entirely absent, and the whole corrosion process consists of hydrogen gas displacement. Consequently the factors which control the corrosion rate of magnesium are different from those of most industrial metals. An important factor is the potential difference across the active electrochemical corrosion cells

which may be of the types metal/film, metal/redeposited metal or metal/impurity. Owing to the relatively low hydrogen overpotential of magnesium, either bare or when covered with films of certain corrosion products, the attack can proceed at considerable speeds in alkali chlorides, even when the metal is highly purified and contains no more than, say, 0.02 per cent. of total metallic impurity. However, traces of certain metals, such as 0.01 to 0.03 per cent. of manganese, may cause considerable increases in the rate, though much larger amounts, say 2 per cent., of this metal, may cut it down. In dilute hydrochloric acid the effect of traces of metallic impurities surprisingly disappears, and since no films of corrosion product are formed in this reagent an explanation is probably to be found in the effect of the impurities upon the films which dictate the potentials of the corrosion cells in salt solutions. If these films be discontinuous, as with small quantities of manganese, the corrosion rate may be increased; if continuous, as with large quantities, the rate is decreased (4).

Effect of Corrosion on Mechanical Properties

We have already published data about the effect of sea-water spray on a number of alloys (5). At first we estimated corrosion merely by loss of weight and visual inspection, but later we found that, from an engineering point of view, these methods were insufficient for the particular elektron alloy AZM in sheet

TABLE VI.

EFFECT OF CHEMICAL COATINGS AND PAINT ON SUBSEQUENT CORROSION OF ELEKTRON AZM ALLOY SHEET.

Size of test pieces 15.6 cm. × 1.5 cm. wide between test marks and 1.6 mm. in thickness.

Treatment.	Ultimate stress. Tons per sq. in.	% Elongation on 2 in.	% Elongation on 1 in.	Loss of weight in grs.
(1) Blanks (not corroded)	19.3, 19.1	18.0, 17.5	16.0, 16.0	—
(2) Ditto intermittent sea-water spray for 4 months	11.8, 11.6	1.5, 2.0	1.0, 2.0	1.25, 1.19
(3) Alum-dichromate process and corroded as (2)	12.8, 13.0	2.5, 2.0	2.0, 2.0	0.75, 0.42
(4) I.G. chromate dip, and corroded as (2) ...	16.1, 15.9	5.0, 4.5	4.0, 4.0	0.05, 0.09
(5) Panalumin process and corroded as (2) ...	13.8, 15.9	2.0, 4.0	2.0, 4.0	0.33, 0.12
(6) Selenium process and corroded as (2) ...	16.7, 16.8	6.0, 6.0	7.0, 6.0	0.03, 0.03

form. This is evident from Table VI, which shows that a protection process which cuts down the loss of weight by 97 per cent. does not similarly cut down the loss of elongation caused by corrosion, and that such a small loss of weight as 0.03 gr. from the whole test bar may be associated with a large reduction in elongation. A similar result had already been reached by the French authors, Hertzog and Chaudron (6), and by Portevin and Bastien (7), for a large range of metals and alloys. They offered the explanation that it was a notch effect set up by the localised corrosion, and showed that it did not occur if the corrosion was uniformly distributed over the bars, and could be eliminated by grinding down the bars till the notches disappeared.

The elektron alloy AM 503 in sheet form is not as sensitive to this effect as AZM. Table VII shows that with a loss of weight of 0.03 grs. the whole of the original elongation may be retained. This is low and it seems that the factors

in the original alloy which cause this are more important than the notching effect of the relatively small amounts of corrosion that have occurred in this test.

TABLE VII.

EFFECT OF CHEMICAL COATINGS AND PAINT ON SUBSEQUENT CORROSION OF ELEKTRON AM 503 ALLOY SHEET. SIZE THE SAME AS AZM IN TABLE VI.

Treatment.	Ultimate stress. Tons per sq. in.²	% Elongation on 1 in.	% Elongation on 2in.	Loss of weight in grs.
(1) Blanks stored for 7 months	12.9, 12.7	5.5, 5.5	5.0, 5.0	—
(2) Blanks corroded by intermittent sea-water spray for 7 months	11.8, 10.7	4.0, 2.0	4.0, 2.0	0.03, 0.38
(3) Alum-dichromate process corroded as (2)	12.3, 12.5	4.5, 5.5	5.0, 7.0	0.02, 0.02
(4) Panalumin process corroded as (2)	13.5, 12.8	5.5, 4.5	6.0, 4.0	0.05, 0.04
(5) I.G. chromate dip, corroded as (2)	12.0, 12.5	3.5, 5.0	4.0, 5.0	0.04, 0.03
(6) Selenium process A, corroded as (2)	12.5, 12.6	5.0, 4.5	5.0, 5.0	0.01, 0.03
(7) Selenium process B, corroded as (2)	12.6, 12.6	5.0, 5.0	5.0, 6.0	0.02, 0.01
(8) Selenium process C, corroded as (2)	12.5, 12.6	5.0, 4.0	6.0, 4.0	0.01, 0.01

Selenium A Treatment.—Dipped in 2 per cent. sodium selenite+20 cc. per litre of orthophosphoric acid at laboratory temperature for 20 secs. Not washed until dry.

Selenium B Treatment.—Initial dip in 1 per cent. chromic acid at 80°C. for 30 secs. and then as Selenium A for 60 secs.

Selenium C Treatment.—Initial dip in 1 per cent. chromic acid at 80°C. for 30 secs. and then immersion in 10 per cent. Selenious acid+0.5 per cent. sodium chloride at laboratory temperature for 30 secs. Washed and dried at 100°.

Some commercially produced castings of AZG alloy gave unsatisfactory results. The test bars were turned from 1in. round rods; one set were 0.564in. in diameter and the other 0.358in. They were treated by protection processes in ways to be described later, sprayed with sea water thrice daily for 30 days while suspended horizontally in a field at Teddington, and finally submitted to a tensile test. The results are shown in Table VIII. The bars possessed little elongation

TABLE VIII.

EFFECT OF CHEMICAL COATINGS ON SUBSEQUENT CORROSION OF ELEKTRON AZG CASTINGS.

EXPOSURE 30 DAYS TO INTERMITTENT SEA-WATER SPRAY.

LARGE.

	Ultimate stress. Tons per sq. in.²	Elongation on 2 in.	Loss of weight in grs.
Untreated, stored ...	8.1, 7.6, 7.0	1.0, 1.0, 0.5	—
Untreated, sprayed ...	6.0, 6.4, 5.9	1.0, 1.0, 1.0	0.66, 0.49, 0.62
I.G. chromate dip ...	6.7, 7.3, 3.7	1.0, 2.0, —	−0.30, 0.53, −0.54
Alum-dichromate ...	6.4, 7.7, 7.4	1.0, <0.5, 1.0	0.17, 0.03, 0.08
Selenium	6.5, 6.5, 7.1	1.0, <0.5, 0.5	−0.01, 0.01, −0.08

SMALL.

	Ultimate stress. Tons per sq. in.²	Elongation on 1 in.	Loss of weight in grs.
Untreated, stored ...	5.8, 5.6, 6.9	1.0, 1.0, 1.0	—
Untreated, sprayed ...	4.1, 7.7, 8.5	1.5, 1.5, 1.5	0.18, 0.06, 0.15
I.G. chromate dip ...	5.1, 5.4, 6.1	1.5, 1.0, 1.5	0.02, 0.05, 0.01
Alum-dichromate ...	9.5, 7.6, 6.9	3.0, 1.5, 1.5	0.06, 0.10, 0.06
Selenium	5.7, 6.6, 7.8	1.5, 1.5, 2.5	0.01, 0.01, 0.01

even before they were sprayed and the tensile strength varied considerably in each set of triplicate tests. These variations were large in comparison with any possible effect which may have been produced by corrosion in the short time of test. Losses of weight were taken at the end of the test by the method adopted throughout of cleaning in boiling 20 per cent. chromic acid with a trace of silver chromate, a solution which has been shown to be without appreciable attack on the alloy (2). Losses in weight varied in each set of triplicates and occasionally actual gains of weight were recorded, due, no doubt, to absorption of liquid by pores in the castings. Possibly, much longer times of exposure would have produced notches sufficiently deep to cause greater effects than the initial variation in the castings themselves; the table as it stands is mainly of interest in showing the poor properties which castings of this composition sometimes possess. The alloy is used for castings for a variety of engine and chassis parts, and for these purposes it is exposed to the atmosphere, often in presence of oil films, but usually in absence of chlorides or intense stresses; in such conditions no protection against corrosion is necessary for reasonably satisfactory service.

Protection Processes for Magnesium Alloys

Much work has been done especially by Boyer (8) and Portevin and Pretet (9) to find some metal or metals which would notably reduce the corrosion of magnesium and increase the strength and yet not seriously increase the weight. This would be the best way of protecting the metal since, even if protection depended on surface film formation, the film might be self-healing in some types of corrosive conditions. The field has been fairly well explored and further important discoveries, though possible, do not seem very likely. Some of the results in practice can be seen in Table III. Manganese is now always used, and most alloys contain aluminium in amounts up to 12 per cent. Zinc, by itself, is not used, but some of the best alloys from a mechanical point of view contain both zinc and aluminium. Where good thermal properties, such as in the manufacture of pistons, are required, copper or cerium are often used, but copper seriously interferes with resistance to corrosion by chlorides or other aqueous solutions.

Failing further progress in making alloys, magnesium alloys will probably be protected against severe corrosive conditions by paints applied over some form of chemically produced film, without which paints are unsatisfactory. The experiments now to be described are concerned with the behaviour of the alloys when sprayed with, or immersed in, sea water, and four methods of producing films suitable for paint bases have been specially studied, namely, the Panalumin or Jirotka process (10), the alum-dichromate process of Sutton and Le Brocq (11), the I.G. Chromate dip (12) and our own Selenium process (5). We shall mention one or two unpublished modifications of the last.

It is easy to produce films on light alloys of magnesium owing to the high reactivity of the metal, but very few of them are of any value. We have tested in a preliminary way the effects produced in more than 500 different solutions, and Mr. Sutton and his colleagues have also made many tests. The alum-dichromate and selenium processes are the residue after drastic elimination, and the former has been tested on a large scale in the R.A.E., Farnborough. These processes have, therefore, some claim to special consideration, but the possibility of the discovery of rival, and even improved, processes is still considerable.

The amount of protection afforded by these processes to sheet AZM alloy is illustrated in the first line of Table XI, which gives losses of weight after four months' exposure to sea-water spray applied thrice daily to the specimens suspended vertically in a field at Teddington.

The selenium process consisted in immersion for 5 mins. at laboratory temperature in 10 per cent. selenious acid solution containing 0.5 per cent. of sodium chloride.

The behaviour of extruded bars 1in. in dia. of alloy VI turned down to cylinders 5 cm. by 2.4 cm., after eight weeks' exposure to similar treatment is shown in Table IX.

TABLE IX.

Treatment.	Losses of weight in grs.
None	2.70; 2.95
Alum-dichromate	0.42; 4.72
I.G. chromate	0.04; 0.48
Selenium process	0.05; 0.09

For this alloy the selenium process consists in immersion for 15 mins. in 10 per cent. selenious acid at laboratory temperature.

Part of the success of the selenium process under conditions of spray is due to a limited power of self-healing which probably occurs in the following way. The magnesium surface becomes coated with a thin layer of magnesium selenide, which is decomposed by water penetrating through pores in the thicker covering layer of selenium. The hydrogen selenide thus formed reacts with oxygen to give selenium, which seals the pores through which the water penetrated.

For alloy AM 503, the selenium process is applied after immersion of the alloy for a few seconds in 1 per cent. chromic acid at 90°C., washing and then immersing in selenious acid, or in a mixture of sodium selenite and phosphoric acid. Results of loss of weight tests at the end of 25 weeks are shown in Table X.

TABLE X.

Losses of Weight of Chemically Treated AM 503 Sheet after 25 Weeks' Intermittent Sea-Water Spray.

Treatment.	Losses of weight in grs.
None	1.26; 1.59
Panalumin	0.23; 0.22
Alum-dichromate	0.15; 0.19
I.G. chromate	0.17; 0.18
Selenium	0.14; 0.14

By the use of sodium selenite acidified with phosphoric acid, decorative films were obtained, the colour ranging from pale gold to red according to the time of immersion; the thicker film could be made a dark purple-black by heating to 90°C., a process which probably converts the selenium to the grey allotrope. Films produced by the selenite bath were rapidly destroyed if washed immediately after removal from the bath; if allowed to drain dry before washing, however, the films became quite stable.

No mechanical tests were made with this set of experiments, but in view of the relatively small effect of corrosion notches on this alloy, as shown in Table VII, the results probably give some indication of the relative value of the protective processes.

In practice, the value of these processes will probably depend on their behaviour as bases for paints. The tests now to be described have also been confined to loss of weight and visual inspection; the great additional expense of mechanical tests was felt to be unjustifiable for the preliminary work and particularly because the tests were mainly regarded as a means of ascertaining the waterproofing powers of paint. Unless a paint can retain its power for long periods, it has little value for magnesium alloys, since evolution of hydrogen beneath porous areas leads to blistering and stripping. After selenium treatment the alloys should be washed in ordinary tap water and then dried in preparation for painting.

Table XI and Figs. 6 to 9 show results on sheet AZM alloy.

TABLE XI.

AZM Sheet Sprayed.

Losses of Weight (grs.).

Paint, etc.	Times of exposure (mths.)	No. of coats.	Selenium. 10% SeO_2 + 0.5% NaCl, 5 mins. Lab. Temp.	Alum-dichromate.	Panalumin (Jirotka).	I.G. Chromate dip.	None
None	4	—	0.16, 0.19	3.52, 3.79	2.66	2.51, 2.66	5.52
Lanoline	4	2	0.61, 0.62	4.20, 5.37	3.62	2.56, 3.18	5.76 other gone
Thermoprene resin ..	5	3	0.21, 0.24	1.75, 2.65	0.83	1.33, 1.77	4.63, 4.73
Duroprene white ...	5	2	0.35, 0.40	3.07, 3.64	5.06	1.01, 1.67	4.32, 5.61
Cellulose and Al ...	5	2	0.65, 0.67	6.81, 7.01	0.97	0.10, 1.36	2.87, 3.48
$ZnCrO_4$; top coat of cellulose and Al ...	12	2+2	0.01, 0.02 (Fig. 6)	0.01, 0.08	0.52	0.02, 0.04	0.50, 0.60 (Fig. 7)

Notes.

Thermoprene resin is obtained from rubber by treatment with sulphuric or sulphonic acids.
Duroprene is a proprietary chlorinated rubber paint pigmented in this case with a mixture of titanium and zinc oxides.
Lanoline was used as a 15 per cent. solution in benzene.
Cellulose and Al. Al = ¼ wt. of cellulose which was a proprietary article of cellulose nitrate and gums.
S treated oil—treated by heating the oil with sulphur chloride and blowing, thus improving the elasticity. This is a proprietary paint.
All paints applied by brushing except lanoline and cellulose, which were sprayed.

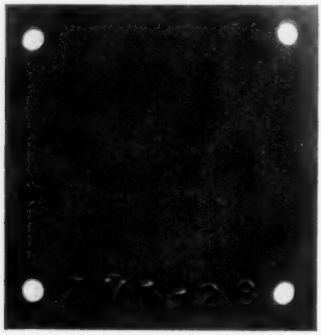


Fig. 6.

AZM alloy selenised and painted; after sea-water spray for 12 months.

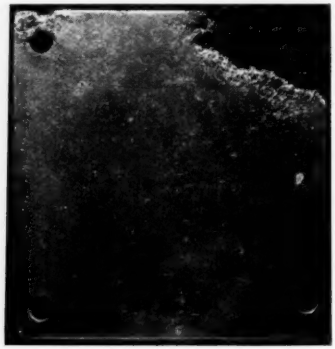


Fig. 7.

As Fig. 6, but without selenium pretreatment.

Lanoline definitely increased the rate of attack compared with bare metal, probably owing to the formation of large adherent drops of sea water after spraying. Clearly lanoline is not always so impermeable as is generally assumed: see Figs. 8 and 9. Some of the paints also increased the attack, but sulphur-treated oil pigmented with zinc chromate and reinforced with a top coating of aluminium pigmented cellulose gave excellent protection for a year, and it is unlikely that much deterioration of mechanical properties had occurred. The selenium film gave relatively good results, both bare and covered with every paint. Other chemical coatings gave more variable results. The I.G. and alum-dichromate processes gave good results with the sulphur-treated oil, but relatively poor results with some of the others. The high resistance to corrosion for a period of one year with all three processes reinforced by the best paint is remarkable.

On thin metal sections the weight of the paint coat amounts to a considerable proportion of the whole. The three coats of zinc chromated tung oil weighed 0.42 grs. and the two coats of pigmented cellulose 0.4 grs.; the weight of the specimen, surface area 50 sq. cms., was 8 grs. Thus the paint coats weighed about 10 per cent. of the whole; their total thickness was 0.08 mm.

TABLE XII.

EFFECT OF PIGMENT IN FINISHING COAT ON AZM SHEET.

Se Treatment: 10% SeO_2 + 0.5% NaCl for 5 minutes at lab. temp.
Undercoat: Two coats of sulphur treated oil and $ZnCrO_4$.

Topcoat (sprayed).	Losses of weight in grs.
Cellulose only (3 coats)	0.06, 0.16
,, + Al (2 coats)	0.09, 0.02
,, + TiO_2 (2 coats)	3.03, 2.70
,, + ZnO (2 coats)	0.53, 1.42

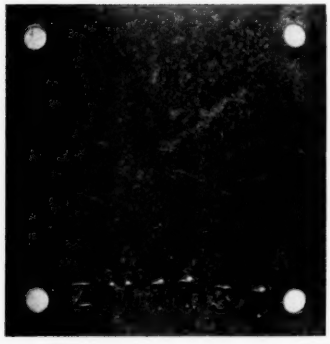


FIG. 8.

AZM alloy selenised and sprayed with sea water for 4 months.

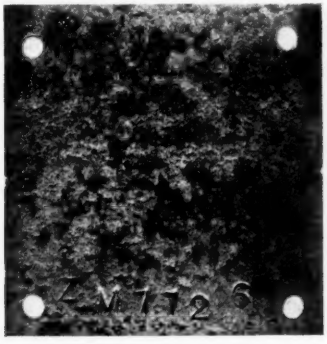


FIG. 9.

As Fig. 8, but with lanoline over selenium coat.

Figs. 6-9, corrosion product and paint removed.

Table XII shows the effect of applying top coatings of cellulose with different pigments, of similar total thickness, over the best under coatings shown by Table XI. The rolled sheet AZM alloy was sprayed with sea water for eight months. Aluminium was the best pigment and zinc oxide was harmful, although in immersed conditions it is sometimes better than aluminium; titanium dioxide caused cracks in the paint and large weight losses.

Table XIII shows the comparative effect of zinc chromate, barium chromate and aluminium powder in four different types of under coatings, using the same top coating in each case. The mediums were proprietary brands to which were added half their weight of chromate or a quarter their weight of aluminium; the paint was filtered when necessary through several thicknesses of muslin and applied by brushing.

Aluminium gave the worst results throughout, probably because local couples were set up; with an insulating medium like thermoprene resin the effect is least noticeable. Zinc chromate was usually much better than barium chromate and, in presence of a top coating, gave almost perfect protection in three of the mediums for the whole time test, 9½ months.

TABLE XIII.

EFFECT OF DIFFERENT PIGMENTS IN VARIOUS MEDIUMS ON SELENIUM TREATED AZM SHEET.

SPECIMENS SPRAYED WITH SEA WATER FOR 9½ MONTHS.

LOSSES OF WEIGHT (GRS.).

	Plain.	Zn chrome.	Ba chrome.	Al.
S treated oil	3.44, 2.52	0.13	1.35, 1.33	4.56, 4.81
+ Cellulose and Al topcoat ...	0.26, 0.06	0.17, 0.19	0.17, 0.16	0.31, 0.67
Berger's clear medium	3.15, 2.96	0.93, 0.35	1.57, 1.39	7.42
+ Cellulose and Al topcoat ...	0.75	0.05, 0.14	0.44, 0.19	0.30, 0.44
Dulux varnish ...	1.79	1.04, 3.16	1.97, 1.63	1.95, 2.33
+ Cellulose and Al topcoat ...	0.65, 0.74	0.02, 0.04	0.27, 0.30	0.84, 1.12
Thermoprene resin ...	—	0.25, 0.48	0.51, 0.22	0.93, 0.82
+ Cellulose and Al topcoat ...	1.46, 1.01	0.00, 0.04	0.13, 0.24	1.05, 0.49

Table XIV gives the results of experiments to find the best selenium treatment for AM 503 alloy as a preparation for paint coats of thermoprene resin and quick drying tung oil. Three other proprietary treatments were also tested by sea-water spraying three times a day for 10 weeks. The corrosion figures in this table are considerably higher than those given in Table X and show that a poor, probably highly segregated, sample of alloy was used: see figures for untreated metal. This alloy is liable to be more variable in its corrosion resistance than either AZM or VI, and may be very good or very bad. The table brings out well the value of appropriate selenium treatment in conjunction with a tung oil base paint, pigmented with zinc chromate, as shown in treatment (5). Figs. 10 to 13 illustrate some of the results.

TABLE XIV.

EFFECT OF PAINTS OVER VARIOUS CHEMICAL COATINGS ON SHEET AM 503 ALLOY, EXPOSED TO INTERMITTENT SEA-WATER SPRAY FOR 10 WEEKS.

Chemical treatment.	Thermoprene resin. 3 coats.	Quick drying tung oil + $ZnCrO_4$ 3 coats.
	Losses of weight in grs.	
(1) 2% Na_2SeO_3 + 6 cc. H_3PO_4/1. Lab. Temp. 5 mins. Not washed until dry	0.07, 0.15	0.24, 0.03
(2) As 1, but 15 mins. immersion	0.12, 0.14	0.05, 0.05
(3) 10% SeO_2 + 0.5% NaCl. 10 secs. Lab. Temp. washed when dry	0.08, 0.50	0.08, 0.04
(4) 5% SeO_2 + 0.5% NaCl. 1 min. Lab. Temp. washed when dry	0.25, 0.64	0.04, 0.04
(5) 1% SeO_2 + 0.5% NaCl. Lab. Temp. 30 sec. Not washed until dry	0.06, 0.28	0.03, 0.02
Alum-dichromate	2.51, 3.94	0.73, 1.43
Panalumin (Jirotka)	2.46, 4.86	0.28, 2.05
I.G. chromate dip	4.15, 4.03	0.98, 0.42
Blanks	Totally disintegrated after about 6 weeks.	3.10, 2.22

None of the other processes gave such good results, but the differences would probably not be so marked with a more homogeneous sample of the alloy. The selenious acid treatment would probably have been further improved by a preliminary chromic acid dip.

Resistance to Immersion in Sea Water

One of the uses proposed for light magnesium alloys is for deck fittings of destroyers and other craft where lightness is important. Such fittings may undergo temporary immersion and any protection process must be adequate to resist this treatment.

TABLE XV.

ALLOY AM 503 IMMERSED IN SEA WATER FOR 21 WEEKS.
EFFECT OF CHEMICAL COATINGS.

Protection treatment.	Losses of weight in grs.
(1) 10% SeO_2 + 0.5% NaCl. Lab. temp. 10 secs. Washed when dry	0.48, 0.81
(2) 10 secs. in 1% commercial CrO_3 solution at 90° and then 10% SeO_2 + 0.5% NaCl. Lab. temp. 1 min. washed ...	0.30, 0.36
(3) 2% Na_2SeO_3 + 6 cc. H_3PO_4/1. Lab. temp. 15 mins. Washed when dry ...	0.67, 0.53
(4) As 3, but 30 secs. in 1% commercial CrO_3 at 90° 1st. Washed when dry ...	0.38, 0.42
Panalumin (Jirotka)	0.15, 0.15
Alum-dichromate	0.18, 0.23
I.G. chromate dip	0.29, 0.32
Blanks	0.59, 0.55

TABLE XVI.

SHEET AZM ALLOY IMMERSED 38 DAYS IN SEA WATER.
EFFECT OF CHEMICAL COATINGS ONLY.

Bath.	Losses of weight in grs.
(1) 10% SeO_2, 2 min. Lab. Temp. ...	0.79, 0.59
(2) As 1, 5 mins.	0.56, 0.59
(3) As 1, 10 mins....	0.70, 0.52
Alum-dichromate	4.28, 4.50
Panalumin (Jirotka)	2.75, 3.54
I.G. chromate dip	2.10, 1.78
Blanks	Totally disintegrated.

Preliminary experiments on alloys AM 503 and AZM in the form of strips 2.9 cms. by 7.0 cms. by 14 S.W.G. immersed in 500 ccs. of sea water showed (Tables XV and XVI) that none of the chemically produced coatings hitherto tested was likely to afford useful protection against prolonged immersion in sea water. It was thought, however, that some paints might do so. These were prepared in the laboratory, and the proportion of pigments was about half the weight of the medium. Three coats were sprayed on to sheet AZM, each being allowed to become hard before the next was applied. The alloy was then immersed in sea water for 28 days. The tests included a number of unpigmented paint media, and then the same medium with either an alkaline pigment, such as zinc oxide or a passivifying pigment, like zinc chromate. The latter sometimes contains considerable quantities of soluble chloride, and the best results can only be obtained with a pigment free from chloride.

FIG. 10.
AM 503 alloy selenised and painted. Sea-water spray for 10 weeks.

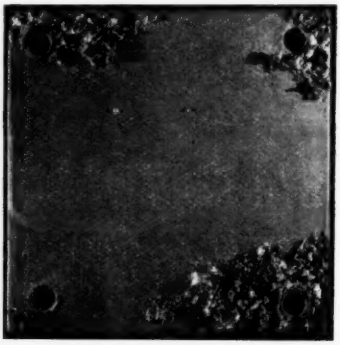


FIG. 11.
As Fig. 10, but panalumin process instead of selenium.

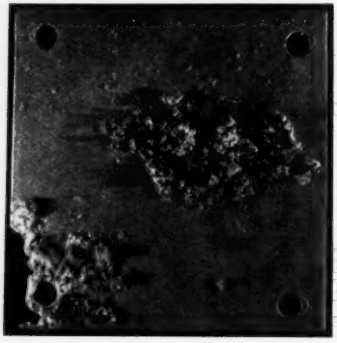


FIG. 12.
As Fig. 11, but I.G. chromate dip instead of selenium.

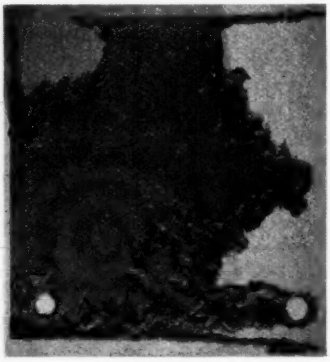


FIG. 13.
As Fig. 10, but painted only.

TABLE XVII.

SHEET AZM ALLOY. TIME OF IMMERSION, 28 DAYS.

EFFECT OF PAINT COATINGS.

Paint composition.	Losses of weight in grs.
Boiled linseed oil and liquid driers ..	1.98, 2.00
Do. + ZnO	1.56, 1.46
Do. + $ZnCrO_4$	0.25, 0.25
Raw tung oil + Co. driers	2.64, duplicate disintegrated.
Do. + ZnO	1.32, 1.69
Do. + $ZnCrO_4$	0.36, 0.32
Sulphur treated oil	2.54, 1.44
Do. + ZnO	0.92, 1.08
Do. + $ZnCrO_4$	0.00, 0.00
Thermoprene resin	1.94, 2.78
Do. + ZnO	0.25, 0.47
Do. + $ZnCrO_4$	0.01, 0.03
Unpainted metal	Totally disintegrated.

Results are shown in Table XVII, the best being obtained with either thermoprene resin or sulphur-treated oil pigmented with zinc chromate.

FIG. 14.

AZM alloy totally immersed in sea water for 4 months. Painted with zinc chromate pigmented sulphur-treated oil only.

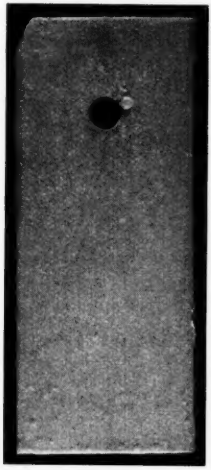


FIG. 15.

As Fig. 14, but with unpigmented cellulose topcoat.

FIG. 16.

As Fig. 15, but cellulose pigmented with aluminium.

FIG. 17.

As Fig. 15, but cellulose pigmented with zinc oxide.

Figs. 10-17, corrosion product and paint in situ.

The next step was to obtain increased protection by the use of a top coating. The thermoprene resin did not take a top coating well, so sulphur treated oil and a quick-drying tung oil base medium were used, both pigmented with zinc chromate; the tung oil medium had the advantage of quicker drying since the process only took a few hours. Results are given in Table XVIII, and some are shown in Figs. 14 to 17.

Protection is much increased by the top coating, which in turn is improved with two of the mediums by the presence of a pigment, particularly zinc oxide which was chosen because of its mild anti-fouling action; the tests show it to be generally superior to aluminium powder. The efficiency of the top coating varies somewhat and was probably affected by climatic conditions during application, such as humidity, temperature, and by the presence of gaseous impurities both during and after application, also by the personal factor, difficulties which are always present in paint research problems. The superiority of cellulose to other top coatings was not so marked as in the spray tests in which it was very decidedly best.

TABLE XVIII.

SHEET AZM ALLOY. TIME OF IMMERSION, 4 MONTHS.

EFFECT OF DIFFERENT TOP COATING.

Three top coatings consisting of :—

	Two undercoats of sulphur-treated oil + $ZnCrO_4$.	Two undercoats of quick drying tung oil medium + $ZnCrO_4$.
No top coating	0.60, 0.45	0.27, 0.34
Unpigmented cellulose	0.01, 0.01	0.03, 0.19
Do. + Al ($\frac{1}{4}$wt. cellulose medium) ...	0.16, 0.20	0.53, 2.02
Do. + ZnO	0.05, 0.10	0.19, 0.25
Unpigmented spar varnish	0.32, 0.24	0.22, 0.11
Do. + Al	0.08, 0.05	0.13, 0.10
Do. + ZnO	0.05, 0.10	0.05, 0.04
Unpigmented thermoprene resin ...	1.50, 0.07	0.20, 0.06
Do. + Al	0.23, 0.17	0.13, 0.02
Do. + ZnO	0.96, 0.40	0.01, 0.07

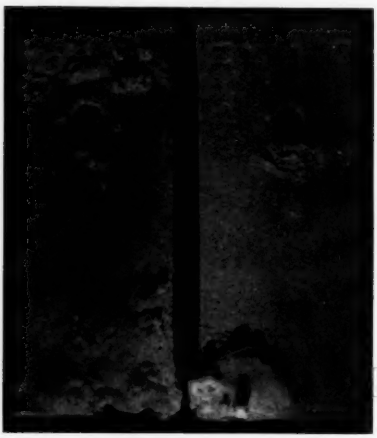


FIG. 18.
Blanks, no chemical pretreatment.

FIG. 19.
Selenium pretreatment.

In consequence of the results shown in Table XVIII, thermoprene resin pigmented with zinc oxide and a spar varnish pigmented with aluminium were tried as top coatings over chemical coatings. Two coats of each were sprayed over a primer of three coats of a quick-drying tung oil medium pigmented with zinc chromate. Results are shown in Table XIX and Figs. 18 to 22.

FIG. 20.
Alum-dichromate pretreatment.

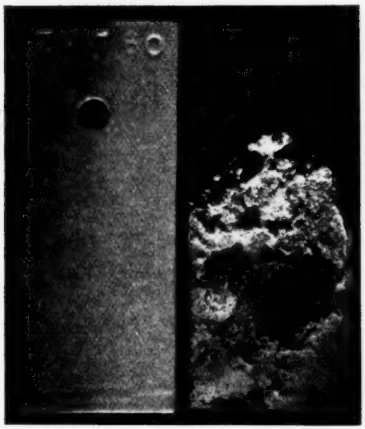


FIG. 21.
Panalumin pretreatment.

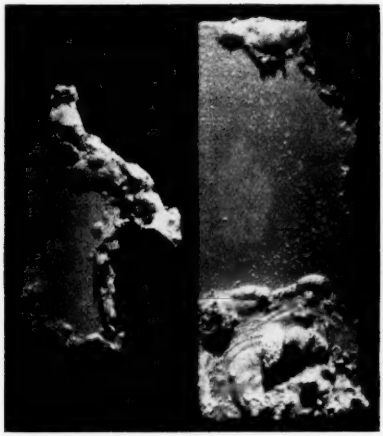


FIG. 22.
I.G. chromate dip pretreatment.

Chemically coated and painted AZM alloy after immersion in sea water for 7 months. Paint and corrosion product in situ. Paint undercoat: quick-drying tung oil pigmented with zinc chromate. Topcoat: spar varnish pigmented with aluminium.

(*Note.—The above applies to Figs.* 18-22 *inclusive.*)

TABLE XIX.

AZM Alloy—Chemically Treated and Painted.

Fully Immersed in Sea Water.

Chemical treatment.	Top coatings of :— ZnO pigmented Thermoprene, immersed for 5 months. Losses of weight in grs.	Al pigmented spar varnish immersed for 7 months. Losses of weight in grs.
10% SeO_2+0.5% NaCl. Lab. temp. 5 mins.	0.14, 0.04	0.34, 0.07
Do., but not washed until dry	0.11, 0.34	0.01, 0.03
15% SeO_2+0.5% NaCl. 10 mins. Lab. temp.	0.05, 0.03	0.00, 0.01
Alum-dichromate process	0.69, 0.72	0.00, 0.51
Panalumin process	0.74, 1.38	0.04, 2.70
I.G. chromate dip	0.05, 0.03	0.61, 4.28
Blanks (no chemical treatment)	0.39, 1.30	0.06, 0.45
Blanks, two undercoats only	0.40, 1.07	—
Blanks, one undercoat only	2.85, 2.99	—

The best results were obtained from the selenium bath at a concentration of 15 per cent. selenious acid. Other pretreatment processes gave inconsistent results, good with one top coating and bad with another. The effect of reducing the number of coats of the primer on the blanks is very marked.

Thermoprene pigmented with zinc oxide showed up as well as spar varnish pigmented with aluminium as a top coating in preliminary tests, Table XVIII, but according to these later results spar varnish pigmented with aluminium is usually better over chemical coatings. The difference is due possibly to the atmospheric conditions at the times of applications of the paint, particularly the humidity. Thermoprene resin is quick-drying, and may therefore have more cooling effect and cause greater condensation of moisture. If this be an important effect a slower drying paint would be better unless the air were very dry.

TABLE XX.

Alloy AM 503 Immersed in Sea Water for 7 Months.

Effect of Chemical Coatings and Paint.

Primer, two sprayed coats of quick-drying tung oil medium pigmented with zinc chromate. Top coatings (1) thermoprene resin pigmented with zinc oxide, (2) a spar varnish pigmented with aluminium.

Chemical pre-treatment.	Paint, top coatings: Losses of weight in grs. 1.	2.
(1) 2% Na_2SeO_3+6 cc. H_3PO_4/1. 15 mins. Lab. temp. Not washed	0.07, 0.13	0.08, 0.02
(2) As 1, but dipped for 30 secs. in 1% H_2CrO_4 solution at 80°C. 1st	0.05, 0.04	0.02, 0.01
(3) As 2, but after treatment, washed	0.04, 0.02	0.02, 0.01
(4) 10 secs. H_2CrO_4 dip and then 20 secs. immersion in 10% H_2SeO_3 solution at Lab. temp.	0.06, 0.00	0.02, 0.01
Panalumin process	0.01, 0.02	0.01, 0.01
Alum-dichromate process	0.01, 0.01	0.01, 0.00
I.G. chromate dip	0.02, 0.02	0.02, 0.01
Blanks	0.10, 0.07	0.23, 0.06

Table XX shows that differences between the two top coatings are not so marked on AM 503 as on AZM alloy, Table XIX. The most striking feature is the small attack on all the specimens. There seems little to choose between any of the pretreatment processes, but the rapidity of the selenium process would appear to be an advantage.

A possible criticism of all these tests on paints is that they were conducted on small specimens. This was necessary because of the high cost of the alloys, and it is fully realised that the unduly high proportion of edge to surface, and the fact that the paints were sprayed, are factors which limit the applicability of the results. It is only claimed that these tests are a useful preliminary exploration of a field which will require much further cultivation.

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THE LOTZ METHOD FOR CALCULATING THE AERODYNAMIC CHARACTERISTICS OF WINGS

BY

B. S. SHENSTONE, M.A.SC., A.F.R.AE.S.

1. *Introductory*

The method generally used in England for calculating the aerodynamic characteristics of wings is that suggested by Glauert (1), in which the circulation across the span of the wing is represented by a Fourier series. On account of the form of the series, certain difficulties arise which make the calculation very tedious when more than about four points along the semi-span are considered. An improvement has recently been suggested by Lotz (2), whose method has the following advantages:—

(*a*) Wings of all possible shapes may be considered with equal ease. In addition to simply curved or tapered plan forms, shapes having discontinuous plans may be accurately considered without the calculation becoming unwieldy. The effect of streamline nacelles and fuselages may be taken into account (3).

(*b*) Any variation whatsoever of incidence or wing section, any sudden break such as is caused by deflected ailerons or floating wing tips can be dealt with.

(*c*) The method is one of successive approximations, the first approximation being obtained with little labour, and great exactitude being obtained with but proportionately greater labour. The calculation is so arranged that any part may be done to any desired approximation, and the degree of approximation is easily determined. The convergence is good, so that for simple shapes the second or third approximation may be considered as exact.

In the present paper the Lotz method is first briefly summarised in the usual English notation. A convenient practical process for carrying out the calculation is then given and is reduced to tabular form so that the wing characteristics may be calculated with a minimum of effort. The process is based on a type of mechanical Fourier analysis adapted from an older method which is apparently little known in this country.*

2. *Outline of Method*

As is now usual, the wing is replaced by a single line vortex, whose vortex strength K at every section is equal to the circulation at that section. The lift per unit length of span is then

$$dL/dx = \rho V K.$$

The problem is to find K for any point on a wing of any shape. If at any point on the wing

$$K = k_L c V = a_1 a_0 c V$$

where $a_1 = a - w/V$

* To carry out the method in practice it is sufficient to follow the outline given in Part 4 of this paper without reference to the preceding theory.

the circulation K is given by the integral equation

$$(1/4\pi V)\int_{-s}^{+s}(\partial K/\partial\xi)\,d\xi/(\xi-x)+K/a_0V_c=\alpha \quad . \quad . \quad . \quad (1)$$

This equation is to be solved for K. The method used by Lotz is briefly as follows:—

In a similar manner to Glauert, the circulation K is expressed as a Fourier series:—

$$K=c_0a_0V\Sigma A_n\sin n\theta \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Then

$$(1/4\pi V)\int_{-s}^{+s}(\partial K/\partial\xi)\,d\xi/(\xi-x)=(c_0a_0/4s)\ \Sigma nA_n\ (\sin n\theta/\sin\theta)$$

and

$$K/a_0Vc=(c_0/c)\ \Sigma A_n\sin n\theta.$$

If the product of the angle of incidence and $\sin\theta$ is expressed as a series in $\sin n\theta$

$$\alpha\sin\theta=\Sigma B_n\sin n\theta.$$

Then equation (1) becomes

$$\Sigma B_n\ (\sin n\theta/\sin\theta)=(c_0/c)\ \Sigma A_n\sin n\theta+(c_0a_0/4s)\ \Sigma nA_n\ (\sin n\theta/\sin\theta) \quad (3)$$

If the wing under consideration is of any shape whatever, as long as it is symmetrical about the centre line of the aircraft in the plan, the expression

$$(c_0/c)\sin\theta$$

can be developed in an even cosine series:—

$$(c_0/c)\sin\theta=\Sigma C_{2n}\cos 2n\theta.$$

Equation (3) then becomes

$$\Sigma B_n\sin n\theta=\Sigma A_n\sin n\theta\ .\ \Sigma C_{2n}\cos 2n\theta+(c_0a_0/4s)\ \Sigma nA_n\sin n\theta \quad . \quad (4)$$

This system of linear equations for the coefficients A_n can, after some rearrangement, be written in the form (5).

$$\begin{aligned}
&B_1-a_0c_0/4s\ .\ 1A_1=A_1\ (C_0-\tfrac{1}{2}C_2)+[\tfrac{1}{2}\{\ A_3\ (C_2-C_4)+A_5\ (C_4-C_6)\\
&\qquad\qquad +A_7\ (C_6-C_8)+\ldots\}\ ]\\
&B_2-a_0c_0/4s\ .\ 2A_2=A_2\ (C_0-\tfrac{1}{2}C_4)+[\tfrac{1}{2}\{\ A_4\ (C_2-C_6)+A_6\ (C_4-C_8)+\ldots\}\ ]\\
&B_3-a_0c_0/4s\ .\ 3A_3=\tfrac{1}{2}A_1\ (C_2-C_4)+A_3\ (C_0-\tfrac{1}{2}C_6)+[\tfrac{1}{2}\{\ A_5\ (C_2-C_8)\\
&\qquad\qquad +A_7\ (C_4-C_{10})+\ldots\}\ ]\\
&B_4-a_0c_0/4s\ .\ 4A_4=\tfrac{1}{2}A_2\ (C_2-C_6)+A_4\ (C_0-\tfrac{1}{2}C_8)+[\tfrac{1}{2}\{\ A_6\ (C_2-C_{10})+\ldots\}\ ]\\
&B_5-a_0c_0/4s\ .\ 5A_5=\tfrac{1}{2}A_1\ (C_4-C_6)+\tfrac{1}{2}A_3\ (C_2-C_8)+A_5\ (C_0-\tfrac{1}{2}C_{10})\\
&\qquad\qquad +[\tfrac{1}{2}\{\ A_7\ (C_2-C_{12})+\ldots\}\ ]\\
&B_6-a_0c_0/4s\ .\ 6A_6=\tfrac{1}{2}A_2\ (C_4-C_8)+\tfrac{1}{2}A_4\ (C_2-C_{10})+A_6\ (C_0-\tfrac{1}{2}C_{12})+[\ldots]\\
&B_7-a_0c_0/4s\ .\ 7A_7=\tfrac{1}{2}A_1\ (C_6-C_8)+\tfrac{1}{2}A_3\ (C_4-C_{10})+A_5\ (C_2-C_{12})\\
&\qquad\qquad +A_7\ (C_0-\tfrac{1}{2}C_{14})+[\ldots]\ .\quad .\quad (5)
\end{aligned}$$

It can be seen that the whole system breaks down into two systems, one of which contains the odd coefficients and the other the even coefficients. If the incidence of the wing is symmetrical about the centre line of the aircraft, only the odd system remains, since all the A_{2n} must equal zero.

For the first approximation, all the terms on the right in the square brackets may be neglected. For the second approximation the results of the first approximation may be substituted in the terms previously neglected, and the solution repeated.

Before the systems (5) can be considered in practice, the coefficients B_n and C_n must be determined. This may be done by the usual methods of harmonic analysis, but this is very tedious. A mechanical method due to L. Herman (4)

has been found to give very good results and can be performed by anyone with a knowledge of simple arithmetic. It is here given in a form specially adapted to the types of series required.

3. *Basis of Mechanical Method of Fourier Analysis**

Given a periodic function of x of period 2π, let $u_0, u_1, u_2, u_3 \ldots u_{n-1}$ be $2n$ equidistant ordinates corresponding to $x=0, 2\pi/n, 4\pi/n \ldots (2n-1)\pi/n$. Then the curve

$$y = a_0 + a_1 \cos x + a_2 \cos 2x + \ldots + a_n \cos nx + b_1 \sin x + b_2 \sin 2x + \ldots + b_{n-1} \sin (n-1)x$$

passes through the tops of the n ordinates if

$$na_r = \sum_{p=0}^{2n-1} u_p \cos rp\pi/n \quad . \quad . \quad . \quad . \quad . \quad (6)$$

and

$$nb_r = \sum_{p=0}^{2n-1} u_p \sin rp\pi/n \quad . \quad . \quad . \quad . \quad . \quad (7)$$

In the case of 20 ordinates the equations are $(n=10)$:—

$$\begin{aligned} a_0 &= (1/20)\,(u_0 + u_1 + u_2 + \ldots + u_{20}) \\ a_1 &= (1/10)\,(u_0 + u_1 \cos 18^\circ + u_2 \cos 36^\circ + \ldots) \\ a_2 &= (1/10)\,(u_0 + u_1 \cos 36^\circ + u_2 \cos 72^\circ + \ldots) \quad . \quad . \quad (8) \end{aligned}$$

and so on.

If $\lambda = \cos 18^\circ$, $\mu = \cos 36^\circ$, $\nu = \cos 54^\circ$, $\varpi = \cos 72^\circ$, (8) becomes:—

$$\begin{aligned} a_0 &= (1/20)\,(u_0 + u_1 + u_2 + \ldots + u_{20}) \\ a_1 &= (1/10)\,(u_0 + \lambda u_1 + \mu u_2 + \nu u_3 + \varpi u_4 - \varpi u_6 - \nu u_7 - \mu u_8 \\ &\quad - \lambda u_9 - u_{10} - \lambda u_{11} - \mu u_{12} - \nu u_{13} - \varpi u_{14} + \varpi u_{16} + \nu u_{17} \\ &\quad + \mu u_{18} + \lambda u_{19}) \\ a_2 &= (1/10)\,(u_0 + \mu u_1 + \varpi u_2 - \varpi u_3 - \mu u_4 - u_5 - \mu u_6 - \varpi u_7 + \varpi u_8 \\ &\quad + \mu u_9 + u_{10} + \mu u_{11} + \varpi u_{12} - \varpi u_{13} - \mu u_{14} - u_{15} - \mu u_{16} \\ &\quad - \varpi u_{17} + \varpi u_{18} + \mu u_{19}) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9) \end{aligned}$$

and so on.

The coefficients in successive a's can be picked out from the circular array shown in Fig. 1, starting every time with the element (1), taking first every

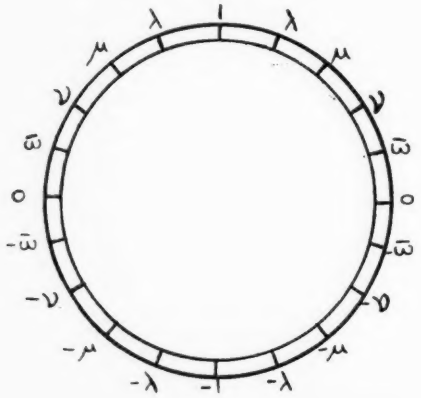

FIG. 1.

* For Part 3 the writer is indebted to Professor R. C. J. Howland.

element, then every second, every third, and so on. The analysis is begun by writing down u_r, λu_r, μu_r, νu_r, ϖu_r, in parallel columns. This will be facilitated if λ, μ, ν, ϖ multiplication tables or graphs are first constructed (see Fig. 5 and Table I). The result is:—

$$\begin{array}{ccccc}
u_0 & \lambda u_0 & \mu u_0 & \nu u_0 & \varpi u_0 \\
u_1 & \lambda u_1 & \mu u_1 & \nu u_1 & \varpi u_1 \\
u_2 & \lambda u_2 & \mu u_2 & \nu u_2 & \varpi u_2 \\
u_3 & \lambda u_3 & \mu u_3 & \nu u_3 & \varpi u_3 \\
\cdot & \cdot & \cdot & \cdot & \cdot \\
\cdot & \cdot & \cdot & \cdot & \cdot \\
\cdot & \cdot & \cdot & \cdot & \cdot \\
u_{19} & \lambda u_{19} & \mu u_{19} & \nu u_{19} & \varpi u_{19}
\end{array} \quad \ldots \quad (10)$$

Every term occurring in the formula (9) occurs somewhere in this five-column table. To find any a or b, the appropriate set is picked out, given either a plus or a minus sign and added.

For this purpose a rectangular stencil is constructed for each a and b. Holes are cut in the stencil in such positions that when it is placed over the array (10) the terms belonging to the corresponding coefficients appear. The holes corresponding to positive terms must be distinguished in some way from those corresponding to negative terms, *e.g.*, a thick line may be drawn around the former. The stencil for a_2 when placed over the table will appear like Fig. 2. The method is very advantageous if a large number of analyses have to be made,

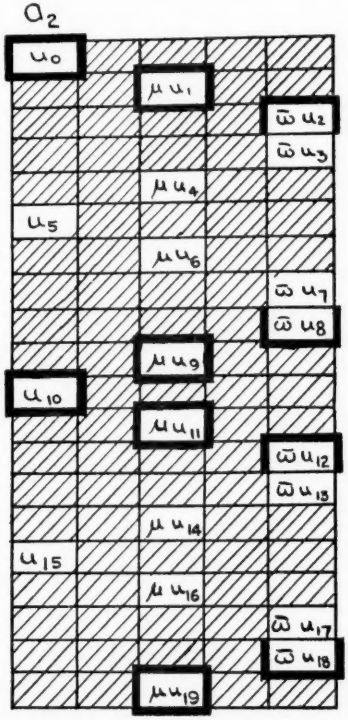

FIG. 2.

since it can be carried out by a computer with no knowledge of the theory and only quite ordinary arithmetical skill.

4. *Application of Method for Calculating the Aerodynamic Characteristics of Wings*

The characteristics which can be found are:—

(*a*) The lift grading for various angles of incidence.
(*b*) The induced drag grading for various angles of incidence.
(*c*) Lift coefficient for given incidence of root section.
(*d*) Induced drag coefficient for given incidence of root section.
(*e*) Pitching moment coefficient for given incidence.
(*f*) Rolling moment coefficient for any incidence in the case of the effective wing twist being unsymmetrical about the centre line of the aircraft.

In practice the method can be carried out in the following form, stencils and forms as shown in Figs. 3 and 4 and Forms I to IV being first prepared.

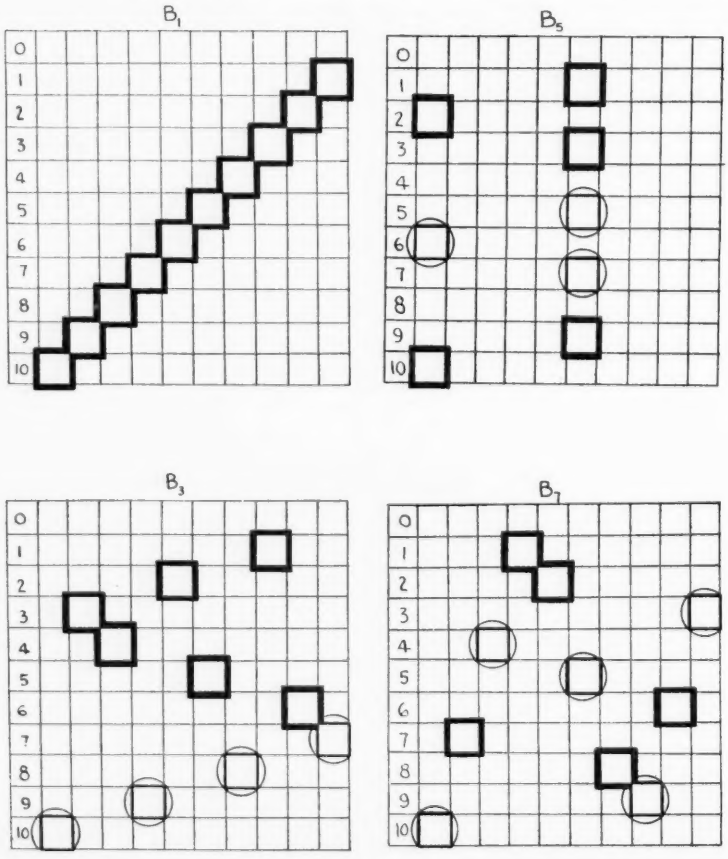

FIG. 3.

(*a*) *Lift Grading.*

Tables and stencils have been prepared for the case when ten points across the semi-span are chosen, and for which the incidence and plan are symmetrical about the centre line of the aircraft. For the case of unsymmetrical incidence, see Part 4 (*f*). If more than ten points are required, suitable tables are quite easily prepared by the method given in Part 3.

(i) *Incidence.*—The coefficients B_n are to be found in the equation

$$\Sigma B_n \sin n\theta = \alpha \sin \theta$$

α being the geometrical incidence (usually measured from the angle of no lift) in radians at any point on the wing. It is usual to take about three values of α_0 the root incidence, say 0, 0.5 and 1.0 radians, in order

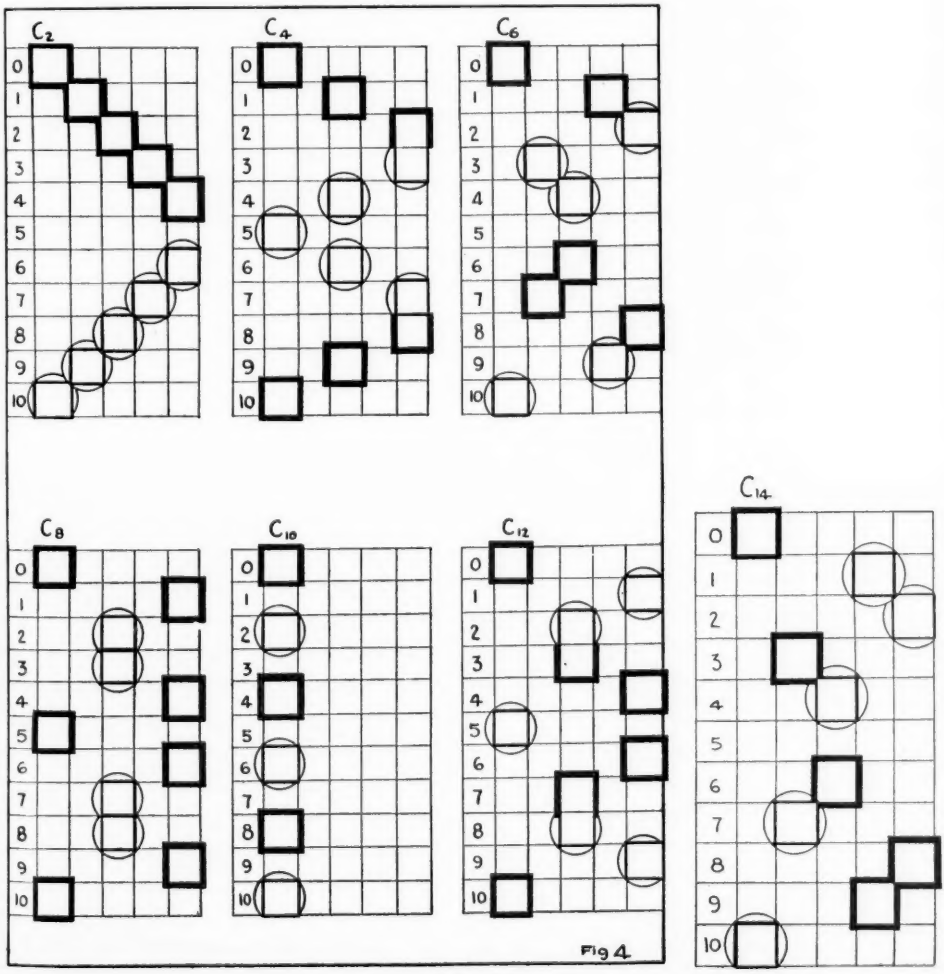

FIG. 4.

finally to draw a curve of A_n on a_0. For each incidence $a \sin\theta$ is calculated for the points along the semi-span given in Table II and written down in Form I, column o. From Fig. 5 or from tables constructed as indicated by the excerpt shown in Table I, Form I is completely filled up. For each B, the corresponding stencil in Fig. 3 is placed on Form I and the values in the thick and in the circled frames transferred to Form II. Following the instructions on Form II, the various values of B_n are thus finally obtained.

FORM I

	0	1	2	3	4	5	6	7	8	9
0										
1	8	8	8	7	6	6	5	4	2	1
2	15	15	14	13	12	11	9	7	5	2
3	25	25	24	22	20	18	15	11	8	4
4	33	33	31	29	27	23	19	15	10	5
5	41	40	39	37	33	29	24	19	12	6
6	48	47	46	43	39	34	28	22	14	8
7	53	52	50	47	43	37	31	24	16	8
8	57	56	54	51	46	40	34	26	17	9
9	59	58	56	53	48	42	35	27	18	9
10	30	½ Ordinate Only in No. 10								

FORM II

		1	3	5	7
THICK FRAMES	1	1	4	6	7
	2	5	12	15	12
	3	11	25	18	14
	4	19	31	42	34
	5	29	29	30	52
	6	39	14		
	7	47			
	8	54			
	9	58			
	10	30			
a	Σ THICK	293	115	111	119
THIN FRAMES	1		8	29	4
	2		34	48	31
	3		53	37	29
	4		30		27
	5				30
b	Σ THIN		125	114	121
a-b		293	-10	-3	-2
$B = \frac{a-b}{5}$		58.6	-2	-.6	-.4
		B_1	B_3	B_5	B_7

$B_1 = +0.586$

$B_3 = -.02$

$B_5 = -.006$

$B_7 = -.004$

(ii) *Plan.*—The coefficients C_{2n} are to be found in the equation

$$\Sigma C_{2n} \cos 2n\theta = (C_0/C) \sin\theta.$$

In this case only one set of plottings is required. Values of $(C_0/C) \sin\theta$ are calculated for the points given in Table II, and placed in Form III. This is filled up from Fig. 5 or table on the lines of Table II, and Form IV is completed similarly to Form II above.

(iii) A_n.—The values of A_1, A_3, etc., are found by filling up Form V as instructed thereon, using the values of B_n and C_n found in (i) and (ii) above. Two approximations are given. Further approximations can be worked out by extending the equation system (5), and/or re-inserting

FORM III

	0	2	4	6	8
0	0	← ½-Ordinate Only in No 0			
1	74	70	60	44	22
2	129	123	104	76	39
3	158	150	128	93	49
4	166	158	135	98	51
5	163				
6	151	144	122	89	47
7	139	132	113	84	42
8	125	119	101	74	38
9	112	106	91	66	34
10	50	← ½ Ordinate Only in No 10			
Σ	1268				

$C_0 = \frac{\Sigma}{10} = 126{\cdot}8$

$C_0 = +1{\cdot}27$

$C_2 = -{\cdot}140$

$C_4 = -{\cdot}466$

$C_6 = -{\cdot}208$

$C_8 = -{\cdot}158$

$C_{10} = -{\cdot}078$

$C_{12} = -{\cdot}07$

$C_{14} = -{\cdot}048$

FORM IV

		2	4	6	8	10	12	14
THICK FRAMES	1	70	60	44	22	166	128	150
	2	104	39	122	51	125	51	122
	3	93	38	132	163		47	38
	4	51	91	38	47		113	66
	5		50		34		50	
	6				50			
	7							
a ΣTHICK		318	278	336	367	291	389	376
THIN FRAMES	1	47	49	39	104	129	22	44
	2	84	135	150	128	151	104	39
	3	101	163	135	113	50	163	135
	4	106	122	66	101		101	132
	5	50	42	50			34	50
	6							
b ΣTHIN		388	511	440	446	330	424	400
a−b		-70	-233	-104	-79	-39	-35	-24
$C = \frac{a-b}{5}$		-14	-46·6	-20·8	-15·8	-7·8	-7·	-4·8
		C_2	C_4	C_6	C_8	C_{10}	C_{12}	C_{14}

the last values found and re-solving. The values of A_n may now be plotted against a_0, and equations of the form

$$A_1 = h_1 a_0 + h_2$$
$$A_3 = h_3 a_0 + h_4$$
$$A_5 = h_5 a_0 + h_6$$
$$A_7 = h_7 a_0 + h_8$$

found. Thus A_n is available for any value of a_0.

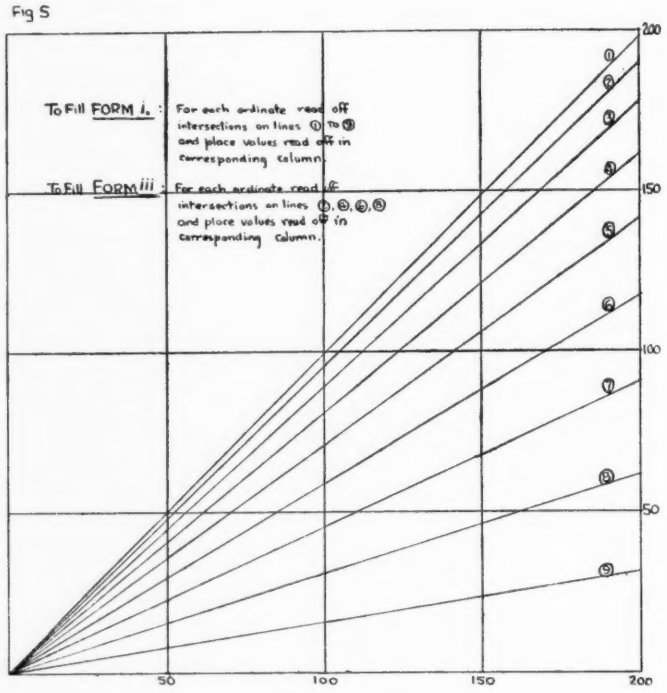
Fig 5
To Fill FORM i. : For each ordinate read off intersections on lines ① to ⑨ and place values read off in corresponding column.
To Fill FORM iii. : For each ordinate read off intersections on lines ①, ⑤, ⑧, ⑨ and place values read off in corresponding column.
200
150
100
50
50
100
150
200

FIG. 5.

TABLE I.

Column	1	2	3	4	5	6	7	8	9
Multiplier	0.9877	0.9511	0.8910	0.809	0.7071	0.5878	0.454	0.309	0.1564
Ordinate									
.	.	.	.	.	.	.	.	.	.
135	133	128	120	109	95	80	61	41	21
136	134	129	121	110	96	80	62	41	21
137	135	130	122	111	97	81	62	41	21
138	136	131	123	112	98	81	63	41	22
139	137	132	124	113	98	82	63	42	22
.	.	.	.	.	.	.	.	.	.

TABLE II.

Fraction of Semi-span	0 (Root)	.156	.309	.454	.588	.707	.809	.891	.951	.988
$\theta°$	90	81	72	63	54	45	36	27	18	9
$\sin\theta$	1	.988	.951	.891	.809	.707	.588	.454	.309	.156
$a°$ for $a_0=0$	0	0	0	−.2	−.7	−1.4	−2.2	−3.3	−4.5	−5.7
a_R for $a_0=0$	0	0	0	−.0035	−.0122	−.0244	−.0384	−.0576	−.0785	−.0995
a_R for $a_0=+.6$	+.6	+.6	+.6	+.597	+.588	+.576	+.562	+.542	+.522	+.50
$a\sin\theta$	+.6	+.593	+.57	+.532	+.476	+.407	+.331	+.246	+.151	+.078
c_0/c	1	1.14	1.32	1.56	1.87	2.30	2.82	3.47	4.17	4.76
$(c_0/c)\sin\theta$	1	1.12	1.25	1.39	1.51	1.63	1.66	1.58	1.29	.743

(iv) *Lift Grading.*—In plotting the lift grading it is usual to do so in a form which is independent of V and such that the curve of k_L across the semi-span may easily be plotted. Substituting $k_L cV$ for K in equation (2), Part 2, results in

$$k_L c/a_o c_o = A_1 \sin\theta + A_3 \sin 3\theta + A_5 \sin 5\theta + A_7 \sin 7\theta$$

which gives the lift grading curve across the semi-span.*

(*b*) *Induced Drag Grading.*

The induced drag grading or distribution is given by the expression

$$k_{Di} c/a_o c_o = (k_L c/a_o c_o)\,(1/\sin\theta)\,(A_1 \sin\theta + 3A_3 \sin 3\theta + 5A_5 \sin 5\theta + 7A_7 \sin 7\theta)$$

the values of A_n and $k_L c/a_o c_o$ being the same as those calculated above.

(*c*) *Lift Coefficient.*

The mean (or overall) lift coefficient of the wing is given by

$$k_L = (\pi c_o a_o/4c_m)\, A_1$$

(*d*) *Induced Drag Coefficient.*

The mean (or overall) induced drag coefficient of the wing is given by

$$k_{Di} = (S/2\pi s^2)\,(\Sigma n A_n^2/A_1^2)\,k_L^2 = (2/\pi A)\,(\Sigma n A_n^2/A_1^2)\,k_L^2.$$

(*e*) *Pitching Moment Coefficient.*

This can be determined in exactly the same method as described in A.P. 970 (1), Chapter VIII, para. 31-39. Instead of equation (5) in A.P. 970, the equation in (*a*) (iv) above is used. Since the relation between Glauert's coefficient A'_n and the A_n of Lotz is

$$A'_n = (c_o a_o/4s)\,.\,A_n.$$

It is seen that if the equation in (*a*) (iv) is multiplied by $c_o a_o/4s$ it becomes identical with that in A.P. 970.†

(*f*) *Rolling Moment.*

In usual practice a rolling moment occurs only when the effective wing incidences on each side of the centre line of the aircraft are unequal. This causes unequal lifts and a resulting moment about the longitudinal axis of the aircraft. When the incidences are unequal, the coefficients B_2, B_4, B_6, etc., are not zero. The incidence must be considered across the whole span instead of across the semi-span. Forms I to V are therefore no longer applicable. However, from Part 3 extended forms may easily be arranged to suit. The rolling moment coefficient is

$$k_l = (\pi/16)\,A\,.\,a_o A_2.$$

As rolling moments are usually caused by the deflection of ailerons, it is necessary to find the effective change of geometrical incidence of a wing caused by the movement of such a flap. For small and medium angles of plain ailerons, reference (5) provides the necessary data. For larger angles and for ailerons of special form (Frise, slotted, Zap, Junkers, etc.) wind tunnel tests must be studied.

5. *Numerical Example*

As an illustrative example, the Lotz method has been applied to the wing shown in Fig. 6. The work has been shown for one value of the root incidence

* The expressions given by Lotz in Part III of her paper (Reference 2) for the lift, induced drag and rolling moment coefficients are for rectangular wings only, although that fact is not clearly stated.

† Of course a direct transformation or comparison of coefficients calculated by the two methods is only allowable when the same number of points across the semispan have been considered by both methods.

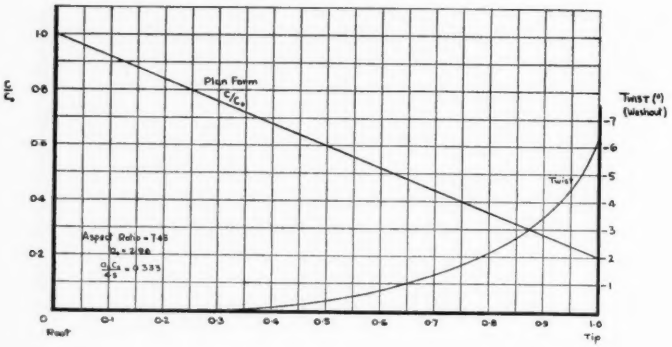

FIG. 6.

FORM Za

Case Approximation 1

$\frac{a_0 C_0}{4S} = 0.333$

$C_0 = 1.27$ $C_2 = -.14$ $C_4 = -.466$ $C_6 = -.208$ $C_8 = -.158$ $C_{10} = -.078$ $C_{12} = -.07$ $C_{14} = -.048$

$\frac{1}{2}C_2 = -.07$ $\frac{1}{2}C_6 = -.104$ $\frac{1}{2}C_{10} = -.039$ $\frac{1}{2}C_{14} = -.024$

$C_0 - \frac{1}{2}C_2 + \frac{a_0 C_0}{4S} = 1.673 = p$

$C_0 - \frac{1}{2}C_6 + 3\frac{a_0 C_0}{4S} = 2.373 = p_3$

$C_0 - \frac{1}{2}C_{10} + 5\frac{a_0 C_0}{4S} = 2.976 = p_5$

$C_0 - \frac{1}{2}C_{14} + 7\frac{a_0 C_0}{4S} = 3.624 = p_7$

$C_2 - C_4 = +.326$ $C_6 - C_8 = -.05$

$C_4 - C_8 = +.018$ $C_8 - C_{10} = -.388$

$C_6 - C_6 = -.258$ $C_1 - C_{12} = -.07$

	α_0 (Radians)			+0·6
1	B_1			+·586
2	B_3			−·021
3	B_5			−·006
4	B_7			−·004
5	$A_1 = B_1/p_1$			+·35
6	$\frac{1}{2}(C_2 - C_4)A_1$			+·057
7	$B_3 - ④$			−·077
8	$A_3 = ⑦/p_3$			−·0324
9	$\frac{1}{2}(C_2 - C_8)A_3$			−·000292
10	$\frac{1}{2}(C_4 - C_6)A_1$			−·0452
11	⑨ + ⑩			−·0454
12	$B_5 - ⑪$			+·0394
13	$A_5 = ⑫/p_5$			+·01325
14	$\frac{1}{2}(C_6 - C_8)A_1$			−·00875
15	$\frac{1}{2}(C_4 - C_{10})A_3$			+·00628
16	$\frac{1}{2}(C_2 - C_{12})A_5$			−·00464
17	⑭ + ⑮ + ⑯			−·00293
18	$B_7 - ⑰$			−·00107
19	$A_7 = ⑱/p_7$			−·000295

only, but it is understood that in this case (a twisted wing) more than one value is necessary to enable the full characteristics to be obtained. Table II carries the calculation up to the Fourier analyses. These are shown in Forms I to IV. For simplicity in the arithmetic the decimal points have been displaced for this part of the work.

FORM Vb

Case: Approximation 2

	α_0 (Radians)			+0·6
1	$(C_1-C_9)A_3$			−·0106
2	$(C_4-C_{11})A_5$			−·00342
3	$(C_6-C_8)A_7$			negligible
4	① + ② + ③			−·014
5	$\frac{1}{2}$ × ④			−·007
6	B_1 − ⑤			+·593
7	A_1 = ⑥/p			+·354
8	$(C_2-C_8)A_8$			+·000238
9	$(C_4-C_{10})A_7$			+·000114
10	⑧ + ⑨			+·00035
11	$\frac{1}{2}$ × ⑩			+·00018
12	$\frac{1}{2}(C_1-C_9)A_1$			+·0577
13	B_3 − ⑫			−·0787
14	⑪ + ⑬			−·0785
15	A_3 = ⑭/p_3			−·0351
16	$\frac{1}{2}(C_2-C_{10})A_7$			negligible
17	$\frac{1}{2}(C_2-C_8)A_9$			−·000399
18	$\frac{1}{2}(C_4-C_8)A_1$			−·0456
19	⑰ + ⑱			−·0458
20	B_5 − ⑲			+·0398
21	⑳ + ⑯			+·0398
22	A_5 = ㉑/p_5			+·0134
23	$\frac{1}{2}(C_6-C_8)A_1$			−·00885
24	$\frac{1}{2}(C_4-C_{10})A_9$			+·00645
25	$\frac{1}{2}(C_2-C_{12})A_5$			−·00047
26	㉓ + ㉔ + ㉕			−·02187
27	B_7 − ㉖			−·00113
28	A_7 = ㉗/p_7			−·000312

The values of $\alpha \sin\theta$ are worked through Forms I and II, and the values of $(C_0/C)\sin\theta$ through Forms III and IV. These values must be so arranged in column (0) of the tables that the wing tip value is in line (1) and the root value in line (10). These forms are filled out as described in Part 4. Form V*a* shows the calculations for the first approximation to A_n and Form V*b* the second. These are self-explanatory. When the values of A_n have been found, the work is quite straightforward, as it is only a matter of substitution in the various expressions given in Part 4.

In conclusion the writer wishes to express his indebtedness to Professor R. C. J. Howland for valuable help and advice in preparing this paper.

Symbols

L = Lift on wing.
D_i = Induced drag of wing.
x = Distance along wing span measured from centre line of aircraft.
K = Circulation around wing.
V = Air velocity relative to wing.
A = Aspect ratio of wing $(4s^2/S)$.
s = Semi-span of wing.
S = Total plan area of wing.
w = Induced velocity.
c = Chord of wing.
c_m = Mean chord of wing $(S/2s)$.
c_0 = Chord of wing at root.
$a_0 = dk_L/d\alpha$ at infinite aspect ratio $= \pi$ (theoretically).
A_n, B_n, C_{2n}, A'_n = General forms of coefficients in Fourier series.
k_L = Lift coefficient $= L/\rho V^2 S$.
k_{Di} = Induced drag coefficient $= D_i/\rho V^2 S$.
k_M = Pitching moment coefficient = pitching moment $/\rho S c V^2$.
k_l = Rolling moment coefficient = rolling moment $/\rho S s V^2$.
α = Incidence of wing at any point on span.
α_1 = Effective angle of incidence of wing.
α_0 = Incidence of wing at root.
Cos $\theta = x/s$. When $x = -s$, $\theta = 0$. When $x = s$, $\theta = \pi$.
ξ = Co-ordinate of variable point on the span.

NOTE.—The symbols used in Part 3 of this paper are not given above as they are defined where used.

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REVIEWS

Theory of Functions as Applied to Engineering Problems
Edited by R. Rothe, F. Ollendorf and K. Pohlhausen. Translated by A. Herzenberg. Technology Press, Massachusetts Institute of Technology, 1933. $3.50.

To the average engineer, the subject of the theory of functions is one which he does not contemplate studying or being of much value. But the modern engineer is learning more and more the value of mathematical methods and their direct application to engineering problems, which have become much more complex than those which faced engineers of the last century.

The sub-title of this book is "As Applied to Engineering Problems." The book is a translation from the German of the well-known work by Rothe, Schottky, Pohlhausen and others, and is divided into two parts. In Part I, complex quantities and variables, line integrals, integrations in the complex plane, Laurent's series and miscellaneous theorem are discussed and proved. In Part II, applications of the theorems given in Part I are given, and in particular the section by K. Pohlhausen on two-dimensional fields of flow is of value to the aeronautical engineer. It deals with the application of function theory to the two-dimensional flow of ideal liquids, leading to flow round a plane plate and the Joukowsky profiles.

The Massachusetts Institute of Technology is to be congratulated upon making available an English translation of a book which should prove of great value to all those who are concerned with the aerodynamics of aircraft. The book is not only exceedingly well translated, but it contains an indispensable bibliography in the text. It is a book which can be confidently recommended.

A Catalogue of British Scientific and Technical Books
Published by the British Science Guild. Price 20/-.

This catalogue consists of a list of scientific books published by British firms up to September, 1929, and it is arranged in a manner which is very convenient for reference. Everyone who has had occasion to investigate some matter outside his usual experience has met the difficulty of finding the appropriate books to consult. The author catalogue so often found in libraries is useless, as the names of writers on the matter to be investigated are often unknown to the enquirer, and it is pleasant to see that in this volume so much attention is given to the Subject Index, which enables a suitable book to be selected. There is also an extensive index of authors' names.

The scope of the catalogue extends over a very large field, both of applied and true science. Philosophy is, for instance, represented by 500 references, and architecture and graphic arts by 400. On the other hand, there are several references to witchcraft. The only omission noticed is in connection with ordnance and gunnery, which are not referred to in the Subject Index. There is a curious error in the spelling of the word meteorology on page 271. There are numerous references to aeronautical literature, but this subject suffers somewhat from the rapidity with which it is developing, as many important books have been published since 1929, but the list given up to that date is thoroughly representative.

The book is particularly well arranged, and it is easy to find the references to any subject which may be required. It is a work which those interested generally in scientific matters will find to be invaluable.

The War in the Air

Vol. IV. By H. A. Jones. Published by Mr. Milford at the Clarendon Press. Price 17/6.

This volume commences with the subject of "Aircraft with the Fleet, 1917-March, 1918," with the unrestricted U-boat warfare and with the air operations from Dunkirk in 1917 and the beginning of 1918. It continues with details of air operations during the Battles of Messines, Ypres, Menin Road Ridge, Cambrai, the Somme, 1918, and Lys.

The air operations connected with the Fleet are concerned with the time when land machines were beginning to be used at sea in place of seaplanes, such as the Sopwith Baby, and the consequent necessity to provide ships with decks from which wheeled aircraft could take-off and land, and it is interesting to note the varying opinion of naval authorities on the subject of the relative importance of gunpower or aircraft. Admiral Beatty was in agreement with the conversion of the light cruiser *Furious* to a seaplane carrier, but wanted to retain the two large 18-inch guns carried by this ship. As a result a compromise was made and a flying deck was fitted in place of the forward 18-inch gun; but experience showed the impossibility of landing on this deck. Eventually it was decided to remove both guns and to fit a complete flying deck, and it seems that this decision marks a turning point in the Admiralty opinion of the relative advantages of guns and aeroplanes.

The decision was largely governed by the success of the Zeppelin in sea scouting, and the consequent necessity for some better means of attacking airships. The improved air performance of the land aeroplanes over the seaplanes previously used gave them a great advantage, and many Zeppelins were successfully brought down.

The use of large flying boats, instigated by Commander I. C. Porte, is fully dealt with, and it is clear that much useful work was done by these boats which could not have been carried out by any other type. Their large range of action and heavy bombs were of great importance in many operations.

With regard to the military operations, the impression given is that the period favoured the development of attacks by aircraft on ground targets rather than actual air fighting, and page after page refers to the effect of our low-flying aeroplanes using 25 lb. bombs and machine-gun fire on enemy formations and batteries. In eight days in March, 1918, no less than 250 tons of bombs, and over 1,000,000 rounds of small arm ammunition, were used against ground targets. The many German reports quoted bear witness to the effect of this intensive bombing on the troops subjected to it, the destruction of stores, wrecking of railways and road transport, and the hampering of supplies which resulted. These results were only obtained at heavy cost, as the wastage of the aeroplanes seems to have amounted to about 30 per cent. per day of the numbers engaged. The delivery of new machines kept up with the wastage, but this easy replacement was possibly connected with the fact that the aeroplanes of this date were constructed of wood and that every small carpenter in the country was manufacturing some component. Whether the modern metal-framed aeroplane could be produced in sufficient numbers to make possible such a method of warfare is very doubtful. But, had it not been for the low-flying aeroplanes, it is at least possible that Amiens would have fallen in March, 1918, and that this might have led to the loss of Paris.

Of the volume itself, it is sufficient to say that it is worthy of the previous volumes and is an invaluable historical record.

Aero Engines—Inspection of, Before and After Overhaul

Sir Isaac Pitman and Sons, Ltd. Price 3/6.

This book is one of a series intended to assist the ground engineer in the performance of his duties and to help him to pass the examinations for his licence. It is recognised by the Air Ministry as a textbook which should be of value to applicants for such licences. The various sections have been written by different authors; the first, on "Inspection of Aero-Engines before Flight," is by Mr. R. F. Barlow.

Starting with a description of the experience and knowledge necessary to become a ground engineer, it continues with a clear and definite account of the various engine details which require attention, and gives the appropriate remedies for the minor troubles which may be found. There is, however, no reference to sparking plugs or high-tension or other leads. Methods of cleaning and setting plug points, and of detecting deterioration in rubber insulation, etc., should be included in future editions.

Mr. A. N. Barrett has dealt extensively with the "Inspection of Aero Engines after Overhaul," and, after explaining the knowledge required of applicants for the "D" licence, goes on to give a lot of useful information about inspection procedure, material specifications, and the usual material defects, following with details of the inspection procedure. His article is an excellent one.

The book concludes with an exposition on the "Law Relating to Civil Aviation," by Mr. A. Isaac.

It is felt that the publication of this book at the low price of 3/6 fills a want which has existed for some time. Not only should the book be in the hands of all ground engineers in the engine categories, but many of those connected with aeroplanes—pilots and others—will find much in it which they ought to know.

Instruments

R. W. Sloley. Sir Isaac Pitman and Sons, Ltd. Price 5/-.

This book is intended for the use of ground engineers in the "X" category. It is one of a series which has been issued for the purpose of assisting the ground engineer in carrying out his work, and is intended to fulfil, therefore, a special and important function.

The instruments considered are: Air speed indicators, engine speed indicators, pressure gauges, fuel contents gauges, radiator and other thermometers, inclinometers, altimeters, watches, turn and bank indicators, and compasses. Its scope is confined, therefore, to the instruments usually found on aircraft.

Mr. Sloley has produced a very useful book. There is no doubt that he understands his subject thoroughly, and his notes on maintenance, methods of checking accuracy, as well as his descriptions of the mechanism of the various instruments, contain a large amount of valuable information which should be of great use to those for whom the book is intended. Occasionally, however, he uses phrases of indefinite meaning, such as, "Such a standard of accuracy has only been reached at the cost of sacrificing a certain amount of robustness, which would be desirable." Sometimes he leaves out information, as when he informs his readers that the A.S.I. requires correction for compressibility of the air at speeds over 200 m.p.h., and then drops the subject. Speeds over this figure will not be unusual in the future, and the correction figures should be given. It is also surprising that he states that small leaks may be permitted on the static side of air speed indicators. Such leaks are certainly much less important than leaks on the pressure side, but what is the definition of "small"?

The book can be thoroughly recommended.

The Casting of Brass Ingots

R. Genders and G. L. Bailey. Published by the British Non-Ferrous Metals Association. Price 15/-.

The contents of this book form an excellent example of the improvements in method which can be made when an old-established process developed by rule-of-thumb is subjected to a scientific analysis and, in fact, the casting of brass, as the opening chapter shows, is one of the oldest of industrial processes.

The ingots dealt with here are intended to be used for the production of brass strip or sheet, and it is of great importance that they should be as free as possible from defects in order that the finished product may be as perfect as possible. With this object, the whole of the process has been subjected to scientific scrutiny in detail—composition of mixture, form of mould, pouring temperature, material of and design of mould, etc., all come under review and the results are given in full. Illustrations showing micro sections, etc., are numerous and are well reproduced.

Although brass is not a metal of great importance from an aeronautical point of view, it is used to some extent in such trades as instrument making, and those engaged in using this metal will find much to interest them here, especially if their plant includes a foundry. The work is a valuable textbook.

The 574th Lecture read before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

A Joint Meeting of the Royal Aeronautical Society and the Institute of Transport was held in the Lecture Theatre of the Royal Society of Arts, at 18, John Street, Adelphi, London, W.C.2, on Thursday, March 1st, 1934, when a paper on "Speed and the Economics of Air Transport," by Major F. M. Green, F.R.Ae.S., M.Inst.C.E., was read and discussed.

In the chair: Mr. H. T. Tizard (Chairman of the Aeronautical Research Committee), supported by Mr. F. Handley Page (Vice-President of the Institute of Transport).

SPEED AND THE ECONOMICS OF AIR TRANSPORT

BY

MAJOR F. M. GREEN, F.R.AE.S., M.INST.C.E.

No one denies that speed is an essential to air travel. It seemed curious to me that air liners were operating at speeds varying from 100 to 150 miles an hour, and some months ago I set out to find a logical basis for determining the most economical speed of flight. I did not expect to arrive at an exact solution; but, rather to my surprise, I satisfied myself that I could give a general answer to most of the problems that interested me. I ventured to submit my calculations in a short memorandum to the Aeronautical Research Committee, and I had the privilege of meeting a sub-committee with whom I discussed my ideas. It was suggested that some further calculations on the same lines would be of interest, and it was proposed by Mr. Tizard, the Chairman of the main committee, that I should send a communication on the subject to the Aeronautical Society. The paper that I am reading to-night is the result of this suggestion.

The methods I shall discuss are engineering rather than strictly scientific. Much of the data I shall use is the result of experience in design; many of the figures on which I base my results are derived from current practice. I shall not attempt to give you an exact answer to the general question, viz., what is the most economical speed of flight? I prefer to give an account of the method I have used so that you can for yourselves calculate the economic speed of operation, using your own knowledge and experience in making the assumptions necessary to this method. In order not to disappoint those of my listeners who do not feel capable of doing this, I am giving a number of tables showing the economic speed of flight for the estimation of which I have used figures that agree with the best current practice as I know it.

In all these estimates of the best speed for air transport the convenience of the passengers in saving time is entirely neglected. Fortunately the cruising speed that I calculate to be the most economical is between 130 and 140 miles an hour, so it is not impossibly slow. Had it been much slower the calculation would have been of academic interest only.

The problem we have to consider is one of economics. An aircraft transport company is in business to earn money for its shareholders; therefore its economic aim is to make profits by selling transport. We will take as our unit of transport

one ton mile of pay load. The number of units of transport each aircraft can provide depends on three factors:—

(*a*) The net pay load in tons.
(*b*) The average cruising speed in miles per hour.
(*c*) The number of hours flown per year.

These three factors multiplied together obviously give the maximum number of ton miles per year possible. The actual revenue earned depends on this figure multiplied by the average rate per ton mile and by the average fraction of the maximum load carried.

(*a*) Of these three factors, the net pay load depends largely on the length of flight. In the analysis that follows, I have for convenience considered that the range in still air is 500 miles. It should be noted that net pay load means only the weight of passengers, luggage, freight and mails that earn revenue. It excludes crew, wireless and equipment generally, although it would be fair to include the weight of refreshments that are sold during the flight.

(*b*) The average cruising speed is lower than the average airspeed, on account of wind and other things. The faster the air speed, the less will this difference be. I have not attempted to assess the advantage that the faster aircraft has in this respect except, to mention it helps to offset other factors mentioned later.

(*c*) The number of hours flown in a year is assumed to be constant. If the length of stages is fixed, the faster craft will do more journeys in the year and will spend more time on the ground in consequence. This will be balanced to some extent by the smaller loss of time due to wind.

It may be objected that, as flying is by fixed stages, a faster aircraft may not gain enough time to do an extra stage in the day; that in consequence the number of hours flown will be less. It may equally well happen that the faster aircraft will be able to start on an extra stage at a time of day that does not allow the slower aircraft to reach its destination before dark. On the average, this sort of thing balances out and the general assumption that the total number of hours flown in a year is constant is not likely to be wrong to any extent.

The amount of money that passengers are willing to pay, and their likelihood of choosing air transport depends greatly on the speed, comfort, safety and punctuality of the service. No attempt is made to allow for this. I have assumed that all the aircraft considered are equal in all respects except speed, and I shall leave it to the operator to decide how much economy he deems it necessary to sacrifice for speed to attract fares.

Few, if any, air lines can pay at present without some form of subsidy. If this is a percentage on the traffic receipts, then the analysis is unaffected. If it is paid on some other basis it must be considered on its merits; it is obviously impossible to generalise except on the former basis.

If we agree with the argument so far, we come to the first conclusion of the analysis, which is to say that *earning capacity is proportional to pay load* × *cruising speed.*

Cost of Operation

In order to find out the profit-making possibilities of an aircraft, we need to know the relation between earning capacity and cost of working. I do not propose to give actual figures; these depend too much on the particular conditions of each route. Fortunately it is enough for our purpose to know the relative costs only, and these can be estimated to a reasonable degree of accuracy in a simple way.

The expense of running an air liner can be divided into two parts:—

(*a*) Standing charges that are independent of flying time.
(*b*) Running costs that depend on hours flown.

These costs can be subdivided into the following main items:—

(*a*) Standing charges, which include—
- (1) Capital charges.
- (2) Obsolescence.
- (3) Aerodrome charges.
- (4) General office and traffic expenses.
- (5) Part of insurance.

(*b*) Running costs, which include—
- (1) Fuel and oil.
- (2) Upkeep of aircraft.
- (3) Upkeep of engines.
- (4) Inspection.
- (5) Wages of crew.
- (6) Part of insurance.

The standing charges depend almost entirely on the first cost of the aircraft, and this again is proportional to the gross weight. It is convenient that aircraft structure and aircraft engines cost practically the same per lb., so that it does not matter if the horse-power is relatively high or low. Standing charges therefore depend on the gross weight of the aircraft.

Running costs for aircraft with the same relative horse-power also depend on weight only, other things being equal. High-powered craft cost more for upkeep, as engine upkeep per lb. is more than for aircraft; also, in a general way, the faster craft use more fuel and oil per mile. It is difficult to allow for this difference in a general way. Fuel varies enormously in cost in various parts of the world, and it is difficult to get reliable figures for upkeep. Fortunately it is not of much importance, for I shall show later that the most economical speed of flight is obtained with engines of a horse-power that is settled from considerations of take-off and flying with one engine stopped.* Consequently the variation in the horse-power weight ratio is too small to affect our general conclusion seriously, viz., that running costs are proportional to weight.

It appears that, as a first approximation, we may make a very convenient assumption, which is that the total cost of operating an air liner is directly proportional to the gross weight. We need only make a reservation that this applies to aircraft whose weight horse-power ratio does not differ much from 15 lbs. per horse-power.

We have seen earlier that the earning capacity is directly proportional to pay load × cruising speed. If we express pay load as a percentage of gross weight, it follows directly that the commercial value of an air liner is directly proportional to the ratio

$$\frac{\text{Percentage pay load} \times \text{gross weight} \times \text{cruising speed}}{\text{gross weight}}$$

for this is the earning capacity divided by running costs. The term gross weight can be cancelled, so that the commercial value of any aircraft is directly proportional to two factors only, which are—percentage pay load × cruising speed. This is the criterion I shall adopt, and I propose to call it the Factor of Usefulness. Expressed another way, it is a number which when multiplied by the gross weight of the aircraft in tons, gives the work in ton miles that can be done in an hour.

Determination of Economic Speed

The method I have used in finding the cruising speed for which to design

* There is one exception to this statement. Twin-engine aircraft intended to fly on one engine only need a much lower horse-power weight ratio than three or four-engine aircraft. They therefore need special consideration.

in order to get the highest Factor of Usefulness is first of all to make a number of assumptions which I believe represent the best modern practice. Based on these figures, I have calculated the pay load for a number of aircraft of different cruising speeds, keeping the range in still air the same—500 miles. I have assumed that the aerodynamic qualities of the aircraft are unchanged by altering the horse-power of the motors, and that the efficiency of propulsion is the same. The aircraft characteristics are fairly correct for an air liner of gross weight from 10,000 to 30,000 lbs.; actually the assumptions are largely based on the experience of design of aircraft of 20,000 lbs. Smaller aircraft are almost outside the range of air liners, and I have little experience of aircraft above the range. The design assumptions I have made are as follows.

Design Assumptions

(1) Range in still air is constant and is 500 miles.
(2) Net pay load excludes crew and special passenger equipment.
(3) An allowance of 25 per cent. of the pay load is added for passenger equipment.
(4) Wing loading is 15 lbs. per square foot for a monoplane of fairly high lift coefficient.
(5) Span loading = gross weight/span^2 = 2.5.
(6) Parasite drag at 100 m.p.h. = 25 lbs. per 1,000 lbs. weight.
(7) Structure weight = 42 per cent. gross weight.
(8) Crew and their equipment, including wireless = 4 per cent. gross weight.
(9) Motor units, complete with starting gear, fairing, silencers, airscrews, piping and oil coolers = 2.5 lbs. per declared h.p.

(Note.—" Declared horse-power " means the maximum horse-power for a 50-hour run at normal speed, and not the maximum horse-power that can be obtained. British type test horse-power is usually 10 per cent. less than maximum permissible horse-power.)

(10) Fuel and oil at cruising speed = 0.54 lbs. per b.h.p./hour.
Tanks for fuel and oil = 0.06 lbs. per b.h.p./hour.
Total of fuel, oil and tanks = 0.60 lbs. per b.h.p./hour.
(11) Propulsive efficiency of airscrew = 75 per cent.
(12) Cruising h.p. must not exceed 75 per cent. of declared h.p.
(13) Minimum type test h.p. for take-off = 62 h.p. per 1,000 lbs.

These assumptions refer to a four-engined unbraced monoplane of good streamline shape. The undercarriage must either be retractable or else extremely well faired. The wing loading of 15 lbs. per square foot is a shade conservative, especially compared with modern American practice. The figure of 25 lbs. drag per 1,000 lbs. weight conforms with the published performance of an aircraft of this type and agrees with my own estimate for a very clean design with well faired air-cooled engines.

I do not expect that a biplane of equally good design would differ very much in its overall characteristics. The profile drag of the wings would be about 20 per cent. less and would probably balance the increase of parasite drag due to struts and wires.

The structure weight assumed is 42 per cent., to which must be added an allowance of 25 per cent. of the net pay load for passenger fittings. This sounds rather high, but it agrees with an average of the modern aircraft I have been able to analyse.

The weight of 2½ lbs. per horse-power for engine units refers to modern air-cooled radial engines and includes all accessories. It is based on British type test horse-power and not on maximum power. Water-cooled units would possibly be a little heavier. Cruising speeds are based on 75 per cent. of type test horse-power, as it is my experience that this is the power at which most engines will run for long periods between overhauls.

Methods of calculating performance are too well known to need description. I wish to thank Mr. W. S. Farren for the time I was able to save by using a method he suggested to me. The horse-power needed for each cruising speed was first calculated and the weight of fuel and oil for a range of 500 miles in still air. This was debited to each hypothetical aircraft together with the weight of the power units necessary to provide the cruising horse-power at 75 per cent.

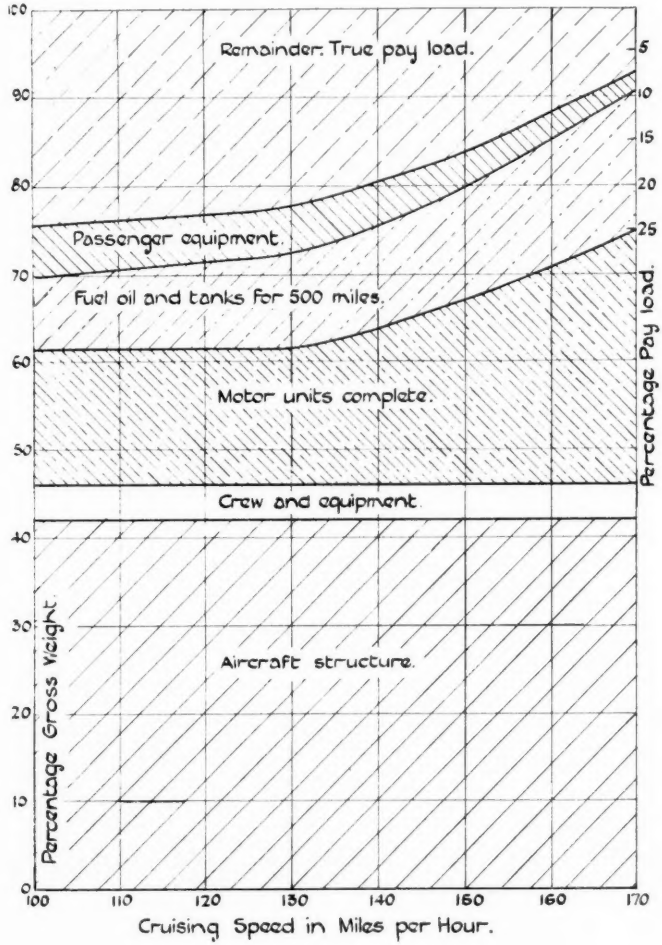


FIG. 1.

of the type test horse-power. The weight of the aircraft structure and of the crew and their equipment was considered to be fixed. All these weights were given as percentages of the gross weight and the remainder is therefore gross pay load. An allowance of 25 per cent. of the gross pay load is considered to be passenger equipment and the net pay load is what is left after this has been deducted. This is shown in Fig. 1, where the results are given in a diagram

which indicates how the weight of the aircraft designed for each cruising speed is split up into its components.

The next step is to multiply the net pay load by the cruising speed to obtain the Factor of Usefulness. Table I gives a summary of these calculations, while Fig. 2 shows the same result expressed as a curve. This diagram gives us the solution to our problem as to what is the economic speed of an aircraft based on our hypothetical characteristics; but it tells us something else as well. The full curve has a sharp peak at 130 m.p.h. There is also a dotted continuation which

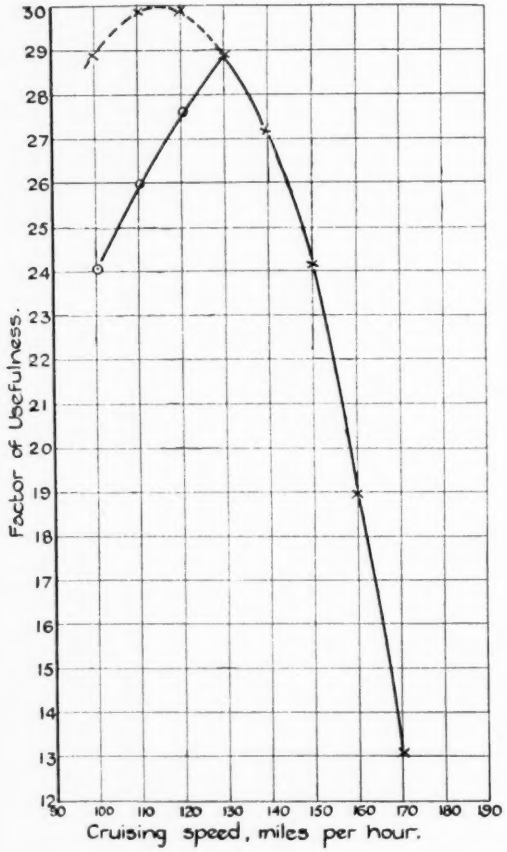


FIG. 2.

represents the Factor of Usefulness of an aircraft in which the maximum horse-power is fixed from considerations of cruising horse-power only. This dotted part of the curve is excluded by the assumption that the minimum power for take-off, climb and flying with one engine stopped demands 62 horse-power per 1,000 lbs. of gross weight.

If we consider a twin-engined aircraft that is expected to fly on one engine only, the minimum gross horse-power must be more than for a three- or four-engined craft. The dotted part of the curve would extend more to the right of

TABLE I.

Cruising speed in m.p.h.		Cruising H.P. per 1000 lbs.	Hours of Flight.	Fuel and Tanks % Gross Weight.	Gross H.P. per 1000 lbs.	Weight of Motor Units.	Weight Less Gross Pay Load.	Gross Pay Load.	Nett Pay Load.	Factor of Usefulness.
100	...	28.2	5.00	8.4	62	15.5	69.9	30.1	24.1	24.1
110	...	33.0	4.55	9.0	62	15.5	70.5	29.5	23.6	26.0
120	...	39.0	4.16	9.8	62	15.5	71.3	28.7	23.0	27.6
130	...	46.5	3.84	10.7	62	15.5	72.2	27.8	22.2	28.9
140	...	54.0	3.58	11.6	72	18.0	75.6	24.4	19.5	27.2
150	...	64.0	3.33	12.7	85	21.2	79.9	20.1	16.1	24.2
160	...	75.0	3.12	14.1	100	25.0	85.1	14.9	11.9	19.0
170	...	87.0	2.95	15.4	116	29.0	90.4	9.6	7.7	13.1

the diagram. This means that for an aircraft of this type the economic speed would be higher, but the Factor of Usefulness would be lower.

The conclusions we can make for our hypothetical aircraft are as follows:—

(1) The most economic speed is 130 m.p.h.
(2) The Factor of Usefulness at that speed is 28.9.
(3) The minimum horse-power for safe take-off, and for climb, and for flying with one engine stopped, is that which should be used for the design of an aircraft in order to obtain the highest Factor of Usefulness.

It might be argued that, since the Factor of Usefulness could be increased by fitting engines of smaller horse-power if other measures were employed to improve the take-off, there is a powerful inducement to use variable pitch airscrews, slots, variable camber and such-like devices. I do not believe that this is true; the possible gain is only from 28.9 to 30 on the Factor of Usefulness scale, which is 3.5 per cent., which would almost certainly be swallowed up by the increase of tare weight due to the devices fitted. Quite apart from this, I think that 130 m.p.h. is just about the minimum speed which operators are likely to adopt out of consideration for what I am neglecting in my analysis, namely, the convenience of the passengers. Conversely, if it is necessary to cruise at a much higher speed there must be an abundance of horse-power, and the objection to a twin-engine aircraft is largely removed. These I think are the reasons that have led to the adoption of such aircraft in America.

We must not forget that the calculations on which we have obtained our results so far depend on a number of design assumptions. I now propose to consider what will be the result if some of our design characteristics are varied.

Influence of Height

The figures given so far apply to aircraft flying in air at standard density; that is to say at very low altitude. Mr. Tizard has already explained the advantages of flying as high as possible to obtain the best fuel economy for a given speed. The best cruising speed will be increased in proportion to the cube root of the density ratio until the engines are working at full throttle and are giving 75 per cent. of their ground type test horse-power. This will occur at a density of 0.8 for non-supercharged engines, while the speed will be increased by 8 per cent. from 130 to 140 m.p.h. This density corresponds to a height of 7,500 feet.

The use of supercharged engines will make it possible to increase the economic speed and the Factor of Usefulness still further. Unfortunately, the rating of such engines is rather involved and there is little experience of their use on regular air lines. This makes it difficult to assess the advantages, as the percentage of their type test horse-power at which they can be run is unknown. From time to time it is suggested that air liners should fly extremely high, and that the cabin as well as the engines should be supercharged. In theory the idea is sound enough, but there are many practical difficulties to overcome.

Influence of Range

Our original assumption fixed the range of our aircraft at 500 miles in still air. Altering the range alters the pay load, but it has only a slight effect on the economic speed, except for extreme ranges that we need not consider. Table II gives the Factor of Usefulness for an aircraft of characteristics similar to the former one, but for ranges varying from 100 to 1,000 miles. It must be remembered that the range of the aircraft must be appreciably greater than the distance between the point of departure and arrival to allow for adverse weather. Fig. 3 shows the same results expressed as curves. It will be noted that it is possible to have the same Factor of Usefulness at 150 m.p.h. as we previously had for 130 m.p.h. by reducing the range from 500 to 300 miles. At the same time, the figure for the 130 m.p.h. craft has gone up from 28.9 to 33.2. This is an

improvement of nearly 15 per cent. The importance of keeping the range down is obvious, but the advantage is somewhat offset by the loss of time on the ground which must result in fewer hours being flown in the year.

TABLE II.

INFLUENCE OF RANGE FACTOR OF USEFULNESS.

Range.	110 m.p.h.	120 m.p.h.	130 m.p.h.	140 m.p.h.	150 m.p.h.
100 miles ...	33·2	35·4	37·5	36·5	34·4
200 miles ...	31·4	33·5	35·3	34·1	31·8
300 miles ...	29·6	31·5	33·2	31·8	29·3
400 miles ...	27·8	29·6	31·0	29·5	26·7
500 miles ...	26·0	27·6	28·9	27·2	24·2
600 miles ...	24·2	25·6	26·8	24·9	21·7
800 miles ...	20·6	21·7	22·5	20·3	16·6
1,000 miles ...	17·0	17·8	18·2	15·6	11·5

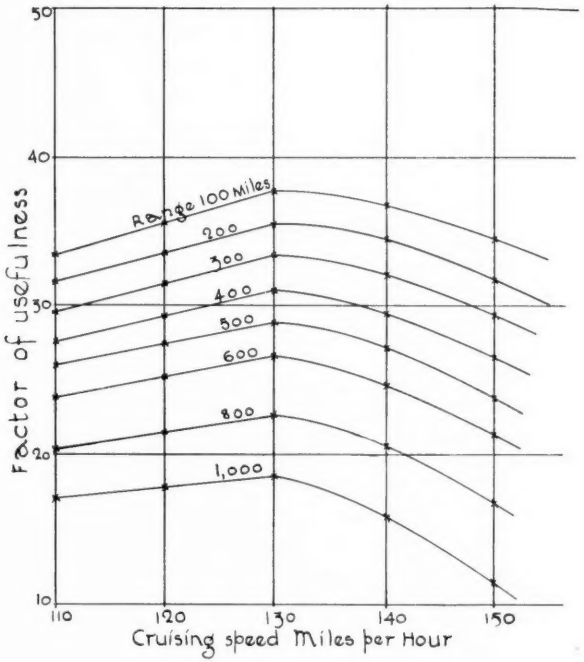


FIG. 3.

Influence of Structure Weight

The structure weight is meant to include that part of the aircraft which consists of wings, body, tail organs, landing gear and controls. The term is rather vague as there has to be an arbitrary distinction between passenger equipment and aircraft structure. I have included an allowance of 25 per cent. of the gross pay load under the heading of passenger equipment, which is meant to cover chairs, windows, luggage compartment, lavatory, etc. The structure weight percentage of the gross weight assumed hitherto has been 42 per cent. During the war we used to base our estimates on a structure weight of 33 to

36 per cent.; but it must be remembered that this referred only to an aircraft stripped to its essentials. Load factors were low throughout, compared with modern practice, while a failure of a landing gear was considered as an every-day incident. Now-a-days such a happening is so rare as to call for a special enquiry.

TABLE III.

FACTOR OF USEFULNESS.

Speed m.p.h.	Structure 42 %.	Structure 36 %.	Structure 30 %.	Structure 25 %.
100 ...	24.1	28.9	33·7	37·7
110 ...	26.0	31.3	36.5	41.0
120 ...	27.6	33·4	39·2	44.0
130 ...	28.9	35.1	41.3	46.6
140 ...	27.2	34.0	40.7	46.4
150 ...	24.2	31.4	38.6	44.5
160 ...	19.0	26.7	34·4	40.9
170 ...	13.1	21.2	29.4	34·5

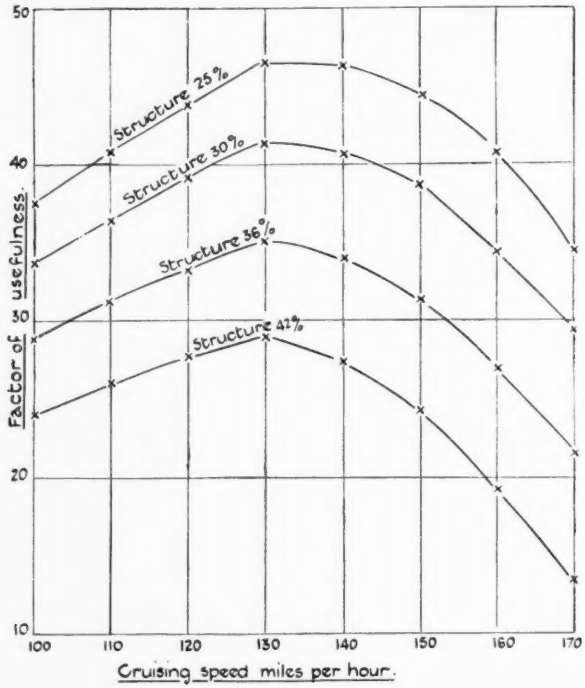


FIG. 4.

I consider that 42 per cent. is a little higher than it need be. For the sake of interest I have prepared Table III, which gives the Factors of Usefulness for lower structure weights. The results are plotted in Fig. 4. It will be seen that the reduction of the structure percentage does not alter the general result in finding the economic speed, but that the optimum point becomes less pronounced as the structure becomes lighter. The Factor of Usefulness is naturally increased;

as an example, a reduction of structure from 42 to 36 per cent. increases the Factor of Usefulness at 130 m.p.h. from 28.9 to 35.1, an increase of 21½ per cent. This might well turn a loss into a handsome profit so long as the saving in weight is made in such a way that upkeep costs are not increased. I think it is rather unlikely that such a big saving could actually be made without some loss of robustness; at the same time, engineers who are responsible for running air services might well remember that a compromise between cost of upkeep and Factor of Usefulness has to be made. The present tendency is rather towards increasing structure weight still further for the sake of increased reliability. Surely it is better to replace such things as hinge pins, brake drums, etc., when they are worn out than to carry the extra weight necessary to make them everlasting.

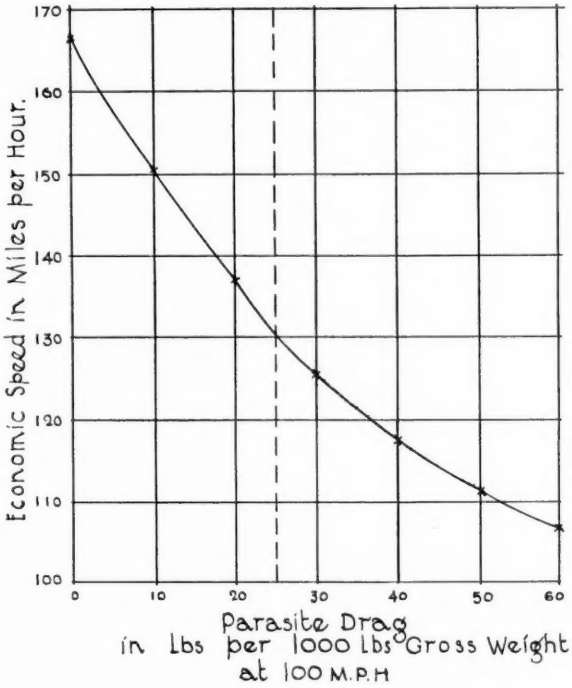


FIG. 5.

Influence of Parasite Drag

The modern tendency is to make all fast-moving vehicles of a shape called streamlined. Up-to-date motor cars and railway trains are trying with more or less success to reduce their windage. The reduction of parasite drag is all-important at speeds of 130 m.p.h. and more. Professor B. M. Jones made the matter perfectly clear in a paper read before this society on "The Streamline Aeroplane," in January, 1929. He showed that for aeroplanes of normal design, the ratio of induced drag to parasite drag was very low at high speeds and he pointed out the enormous saving of power if parasite drag could be reduced to skin friction only.

The figure of 25 lbs. drag per 1,000 lbs. weight at 100 m.p.h. that we have assumed so far, corresponds to a cabin monoplane with the landing gear retracted.

The only portion of the drag that is likely to be reduced is that which arises from cooling the engines, which are assumed to be radial air-cooled engines with the best type of ring cowling available at the moment. I do not think that we shall improve much on this drag unless we use liquid- or steam-cooled engines with wing radiators. This will almost certainly mean heavier power units and increased cost of upkeep. If it is possible to increase the temperature at which we can work air-cooled engines, some gain is also probable.

Fig. 5 shows the increase of cruising speed possible if the parasite drag is reduced, and also the loss of speed when it is increased. It will be seen that with no parasite drag at all, the economic speed rises from 130 to 168 m.p.h., while, if the drag is increased from 25 lbs. per 1,000 lbs. at 100 m.p.h. to 60 lbs., the speed is reduced to 107 m.p.h. As a matter of interest, I might mention that the H.P.42 has a drag in the neighbourhood of the latter figure, and that the Argosy is somewhat worse. The Atalanta is not quite as good as 25 lbs., chiefly because the landing gear is not retractable. The Boeing 247 is about 25 lbs., calculated from the published performance.

I do not suggest that high drag is necessary in biplane design. The de H.82 which is at present undergoing trials is enormously improved in the matter of drag. Performance figures are not yet available, but it may well prove that what has been lost by the comparatively small number of struts and wires is made up by the lower profile drag of the thin biplane wings. The Curtis Condor is another example of modern biplane design; but I have no reliable figures of the performance of this aircraft.

Influence of Wing Loading

It is a constant temptation to all aircraft designers to reduce the size of the main planes—that is to say, to increase the landing and take-off speed. Our original assumption was that 15 lbs. per square foot was as high as it was reasonable to go, for monoplanes, and consequently it ought to be a little lower for biplanes—whose maximum lift coefficient is lower. I have estimated the influence on speed due to alteration of wing loading. Curiously enough, it is almost exactly one mile an hour for a change of 1 lb. a square foot between 12 and 20 lbs. per square foot. This assumes that the size of the body is not altered for the smaller wings. Increasing the loading from 15 to 20 lbs. per square foot results in a gain of 5 m.p.h., which is an increase of not quite 4 per cent. in speed, and slightly more in the Factor of Usefulness. There will be small further gain as the structure percentage will be slightly reduced.

Influence of Wind

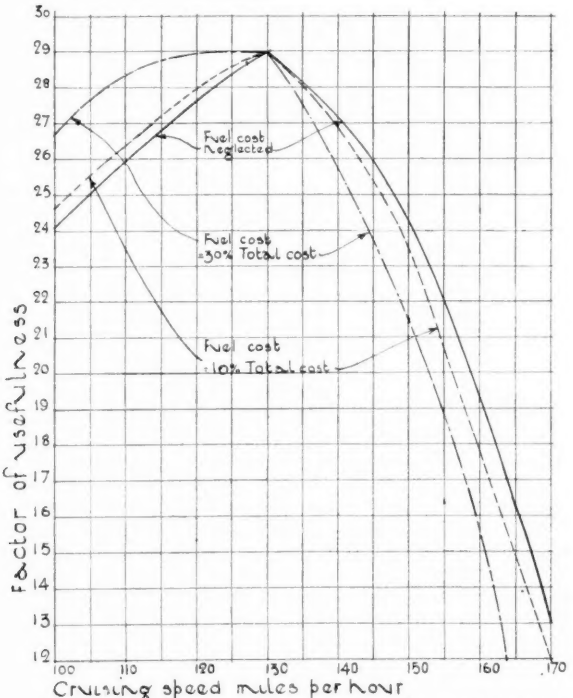
Quite apart from the inconvenience caused by late arrival, the effect of a head wind is to reduce the effective cruising speed and the Factor of Usefulness. The return journey with a following wind does not make up for this, but the faster the aeroplane flies, the less is the loss. This is all in favour of designing aircraft to fly a little faster than the economic cruising speed given in the various diagrams. Against this, we must remember that the higher speed means some increase in the cost of fuel and general upkeep. I do not think, therefore, that the economic speed need be altered for this reason.

The effect of a head wind is to move the speed scale in our diagrams, and it does not affect the best design at which we have already arrived. It is true that the faster aircraft suffer proportionately less for a wind of a given velocity, and therefore their true range is nearer the range in still air. It is customary to provide intermediate landing places so that the aircraft can refuel when the conditions are very bad. This, of course, is not always possible, but it is a serious disadvantage to carry an excess of fuel for emergencies. If we assume that emergency landings are possible, then the only disadvantage of the slower machine is a very occasional loss of time. We must also remember the rapid

decrease in the Factor of Usefulness with more than a small increase of cruising speed.

Influence of Fuel Consumption

The combined fuel and oil consumption at cruising speed was 0.54 lbs. per b.h.p. hour in our original design assumptions. This is about as good as we can hope to get with modern petrol engines using fuel with an octane rating of 73. Using higher compression ratios, which is possible with better petrol, a small decrease of consumption can be expected. When it is possible to use compression ignition engines we can expect a combined fuel and oil consumption at cruising speed of at least 0.4 lb. per b.h.p. hour. Assuming that such engines weigh no more than those which work on petrol, we should get an increase of the Factor of Usefulness due to the increase of pay load on our original aeroplane at 130 m.p.h. from 28.9 to 30. The economic speed will still remain unaltered, but the penalty of flying beyond this speed will be slightly less than before.



Modification of Factor of Usefulness due to cost of Fuel. Fig 6

*Influence of Cost of Fuel**

In a former paragraph on Cost of Operation it is stated that faster aircraft use more fuel per mile; but that it is difficult to allow for this in a general way.

* NOTE.—This did not appear in the lecture as read. It is added for the convenience of those who may read the paper and not the discussion.

Since this paragraph was written, Major Mayo has been kind enough to supply me with information that to some extent gets over the difficulty. He states that on Imperial air routes the cost of fuel is between 25 and 35 per cent. of the total cost of operation. He also stated in an article in *The Times Engineering Supplement* of January 27th, 1934, that the cost of fuel on these routes is nearly three times the cost on American air lines. Using this information, I have calculated the correction to the Factor of Usefulness, allowing for the cost of fuel. I have taken this to be 10 per cent. of the total cost of operating the hypothetical aircraft at 130 m.p.h. when the cost of fuel is a minimum, about $11\frac{1}{2}$ pence per gallon, and alternatively 30 per cent. when the cost of petrol is high as on Empire routes. Fig. 6 shows the result of these corrections.

It will be seen that for the lower cost of fuel there is still a sharp peak in the curve at 130 m.p.h. and that the penalty of flying faster is increased while the loss due to flying slower is slightly less. On the other hand, when the cost of petrol is 30 per cent. of the operating cost, which means petrol between 2s. 6d. and 3s. a gallon, then the curve is flat between 130 and 120 m.p.h., while at 100 m.p.h. the loss in Factor of Usefulness is halved. This indicates that the economic speed is anywhere between 120 and 130 m.p.h., but as the essence of air travel is speed, it is obvious that the higher speed would be chosen.

In the remoter parts of Africa the cost of fuel is more than 3s. a gallon. This is exceptional and justifies a reduction of speed below 130 m.p.h. Fortunately it does not mean that there is any advantage in using aircraft that are intrinsically slower. It is only necessary to fly the same aircraft at a lower cruising speed, using less horse-power.

* * * * *

From the discussion of the effect of changes in the original design characteristics, it appears that the most economic speed is altered chiefly by change in the parasite drag. It can be altered to a considerable extent by flying at various heights and to a lesser extent by changing the wing loading. On the other hand, the Factor of Usefulness can be altered independently by changing the range, the percentage of structure weight and by variation of the specific engine consumption as well as by the alteration of speed caused by varying the three former characteristics.

The aircraft designer has two main things to attack, parasite drag and structure weight. The influence of these two items is so great as to overwhelm all the others. It is true that the aircraft designer can help by making reliable motor units which weigh less per horse-power and which have a lower fuel consumption. Although there has been a tendency for structure weight to increase, due partly to more severe stressing conditions, I think that once it is realised that a comparatively small change may make the difference between commercial success and failure, designers will find ways of reducing it somewhat. I hesitate to make any prophecy; but I believe it will be possible to reduce the percentage from 42 to 38 without increasing the cost of the aircraft to any extent.

The reduction of parasite drag below 25 lbs. per 1,000 lbs. weight at 100 m.p.h. is likely to be very difficult. I think that it would be a great achievement to reduce it to 20 lbs.

Let us be rather optimistic and hope that we shall soon have aircraft with reduced structure weight and parasite drag as in the last two paragraphs. Let us also imagine that the aircraft cruises at 7,500 feet. The economic speed will be 148 m.p.h., while the Factor of Usefulness for a range of 500 miles will be 33, an improvement of 14 per cent.

* * * * *

I have now finished the explanation of a method of assessing the value of an air liner as a commercial undertaking. Those designers who think it to be a reasonable method can put down what figures they expect to get on new designs and they can find out what advance they hope to make on existing practice.

Alternatively, the enthusiasts who demand a minimum cruising speed of 200 m.p.h., or more, can find out what the sacrifice of commercial value is implied. They can then go a stage further and determine the increase of rate per ton mile necessary to make very high speed aircraft profitable. Unless something entirely new is devised in aeronautics, I am afraid that it will be very costly to fly at speeds much above those which I have indicated as economic. At the same time, it is quite likely that there will be a certain amount of freight, such as very urgent mails, for which the public will be willing to pay a rate many times greater than the normal. As air traffic increases the chances of this happening will become greater; some day or other there is sure to be a limited number of these ultra-fast craft, but I do not think they will often be used to carry passengers.

Finally, may I suggest a commercial use of the method with which this lecture has been concerned? If you wish to know how a route can be run at a profit without a subsidy, all you have to do is to find out from the company who are already running a service over a similar route what profits they are making and the percentage of the subsidy of their gross receipts. You next calculate the Factor of Usefulness of the aircraft they are using. If you can then persuade a constructor to supply you with aircraft similar in price but with a Factor of Usefulness greater than those now in use by an amount which is in the same ratio as the net receipts to the gross receipts, including subsidy, you will have solved your problem. All you have to do is to run these aircraft with the same engineering commercial skill and you will automatically earn the same dividends as the subsidised company.

Discussion

The Chairman: Major Green had discussed in a very provocative way a problem of great immediate importance and very great future interest.

An interesting conclusion drawn by Major Green was that, if one did as well as one could do in the way of design, the economic cruising speed of the machine—*i.e.*, the speed at which a company should obtain the greatest net receipts when charging a definite amount per ton mile—was 130-140 m.p.h. Then he had suggested that, so far as he could see, if the structure weight were reduced to a percentage very much smaller than that obtaining to-day, if the parasitic drag were very much reduced, and so on, under no circumstances of that kind would the economic cruising speed be greater than 140 m.p.h. This conclusion, that although, of course, the factor of usefulness might go up tremendously, as shown by Major Green's figures—and it was quite obvious to anyone who thought about it—one was not likely to arrive at an economic cruising speed greater than 140 or even 150 m.p.h., however great a technical improvement might be effected, was of great significance and warranted careful criticism and examination.

Mr. Woods Humphery (Imperial Airways, Ltd.): He congratulated Major Green upon having solved so easily all the problems they had been endeavouring to solve for so many years. To comment really thoroughly on the theory he had presented would involve writing a book on the economics of air transport. One imagined that that was fully appreciated by Major Green, judging by the very easy manner in which he had dismissed, or had not mentioned at all, some of the vital variables which controlled the cost of air transportation. Such things as timetables, for instance, he had dismissed with a wave of the hand; that applied also to the questions of the convenience of passengers and the loads to be carried.

But apart from that, Mr. Woods Humphery was not sure—and he did not think the Chairman was sure—what Major Green really meant by the term "economic cruising speed." If he meant the speed at which goods could be carried at the cheapest possible rate per ton-mile, then Mr. Woods Humphery

could assure him—not from theoretical deduction from hypothetical assumptions, but from fact and experience—that that speed was much below 130 m.p.h. If, however, he had meant the speed which would enable the operator to sell the largest amount of ton-miles, then 130 m.p.h. was somewhere near the mark. But Mr. Woods Humphery had not arrived at that from any aerodynamic calculations; his reasons were purely commercial. Therefore, he was at a loss to understand why Major Green's figure of 130 m.p.h. approximated fairly closely to the figure which he also believed to be the probable cruising speed of air liners of the immediate future. But perhaps the answer was provided by the very easy way in which Major Green had dismissed the really vital questions. For example, it seemed to be suggested in the paper that the cost of fuel and oil had no bearing on the matter. As a mater of fact, however, those items had a vital bearing.

Therefore, he was unable to agree with Major Green's basic assumptions, and in those circumstances it would be valueless, as was suggested in the paper, to comment on the rest of the deductions. However, he thanked Major Green for having put forward for discussion so highly controversial a subject.

Major GREEN: It appeared that the paper had not been understood. The reason why the economic speed arrived at by Mr. Woods Humphery was not 130 m.p.h. was that he used mostly aeroplanes which were not of the type mentioned in the paper; it was necessary to reduce the drag to 25lbs. per 1,000lbs. weight, but in some of his aircraft that was not achieved. Major Green stated quite seriously that 130 m.p.h. was the most economic speed for carrying goods so long as the drag was reduced to the figure mentioned. He agreed that one could not base a timetable on the economic speed; taking the timetable into consideration, the true cruising speed would have to be lower, obviously. But the timetable had not very much to do with his problem, which was to find out the speed at which a ton of merchandise or a ton of passengers or a ton of merchandise and passengers could be carried most economically per mile, and, rather to his surprise, that speed had worked out at 130 m.p.h. That was not the speed he had wanted, but it was the speed he had arrived at from his figures, and it came out quite clearly; so far as he could see, he had not missed anything. He had not said that the amount of petrol used did not matter, but that 130 m.p.h. was also the speed which would give the best petrol consumption figures. He had said that if the machines flew faster than that they would use more petrol—though he was not able to assess exactly how much more would be used—but that as the h.p. was settled by other considerations it did not matter much. He could assure Mr. Woods Humphery that when he had reduced the drag on his aircraft to 25lbs. per 1,000lbs. weight, as undoubtedly he would do very soon, he would find, to his surprise, that he could fix his timetable on the basis of about 120 m.p.h., and his aircraft would fly at about 130 m.p.h.

Mr. WOODS HUMPHERY: The words used in the paper were:—" Fuel varies enormously in cost in various parts of the world, and it is difficult to get reliable figures for upkeep. Fortunately, it is not of much importance . . . ."

Major GREEN: It was not of much importance in his analysis, because, fortunately, the amount of petrol used at a speed of 130 m.p.h. was about the minimum. If one were making a comparison of 130 with 150 m.p.h. it would have been of importance; the minimum consumption figure was not affected by the cost of petrol.

Major R. H. MAYO, F.R.Ae.S.: He congratulated the lecturer on his courageous attempt to solve the major problems of air transport by a stroke of the pen. He said that as an old friend of Major Green he found it somewhat painful to make the rather serious criticisms of the paper which he proposed to make, but he hoped it would be realised that those criticisms were not made in a contentious or destructive spirit.

The general conclusion which Major Green had reached, that very high cruising speeds were commercially impracticable, was quite obviously correct,

but this was so well realised by those interested in air transport that it was not even controversial. But he ventured to say that that was about the only one of Major Green's conclusions which would stand the test of analysis.

There were many statements and assumptions in the paper with which he did not agree, but he would confine his remarks to the broad principle on which the paper was based. Major Green's criterion for the usefulness of a commercial aircraft, which he had termed the " Factor of Usefulness," was fundamentally incorrect. Major Mayo did not mean that it was merely inaccurate, but that it was basically wrong and entirely misleading. This so-called " Factor of Usefulness " was intended to represent the ratio of earning capacity to running costs. If it did so it might fairly be termed the " Factor of Usefulness," but in fact it did not get within measurable distance of doing so.

Major Mayo agreed that the earning capacity might be taken as roughly proportional to the paying load capacity multiplied by the cruising speed, although in fact the air transport operator must take into consideration a number of factors which might materially affect this assumption. On this assumption the numerator of Major Green's fraction, namely, percentage pay load × gross weight × cruising speed did represent the earning capacity on a time basis.

The denominator, which was intended to represent the total running costs, was made up of the two components " standing charges " and " running costs." He agreed that Major Green was not very far wrong in his conclusion that " standing charges " depended on the gross weight of the aircraft. He pointed out, however, that both aerodrome charges and general office and traffic expenses depended also on the number of journeys made, or, in other words, on the cruising speed of the aircraft. Again, Major Green's statement that aircraft structure and aircraft engines cost practically the same per lb. was only a very rough approximation to the truth; no air transport company could in fact afford to budget on so rough an approximation. But, as he was dealing with the broad principle of Major Green's formula, he would not pursue this point further.

When one came to running costs Major Green's assumptions began to go seriously astray. According to Major Green, the running costs comprised six items, and, having enumerated these items, he had skated lightly over most of the major problems of air transport in a single paragraph, reaching the amazing conclusion that running costs were proportional to the gross weight of the aircraft. Major Mayo dealt with these six items individually, to show that only one of them was even approximately proportional to the gross weight of the aircraft alone.

(1) *Fuel and Oil.*—This was not proportional to the gross weight at all, but to the cruising power.

(2) *Upkeep of Aircraft.*—This was by no means proportional to the gross weight alone. It also depended to a very important extent on the miles flown. Once an aircraft was in the air there was comparatively little wear and tear upon it; the wear and tear arose largely from taking-off, landing and taxying. Thus, the number of flights made had a very important effect, and since Major Green had assumed the number of hours flown in a year and the length of stages to be constant, it followed that this time for upkeep of aircraft was dependent not only on the gross weight, but also on the cruising speed.

(3) *Upkeep of Engines.*—This item had no relationship to the gross weight of the aircraft. It depended mainly on the cruising power and the cruising speed. The reason it depended on cruising speed was that the heaviest wear and tear on the engines occurred during the processes of taking-off and initial climb and, on the assumptions Major Green had made, the number of such take-offs was proportional to the cruising speed.

(4) *Inspection.*—For reasons similar to those stated with regard to (2) and (3), this item was also dependent on the cruising speed as well as the gross weight.

(5) *Wages of Crew.*—These were partly dependent on the gross weight, but partly also on the paying load capacity. The number and functions of the crew would depend not only on the size of aircraft but also on the number of passengers carried. Obviously, one first-class pilot must always be carried, but the remainder of the crew would vary with the number of passengers.

(6) *Part of Insurance.*—This would be roughly, but by no means accurately, proportional to the gross weight.

Thus, three important items of the six were dependent on the cruising speed; and the most important item of all, namely, fuel and oil, was not proportional to the gross weight at all, but to the cruising power.

In the remarkable paragraph in which Major Green had so lightly dismissed many of the major problems of air transport it was stated that " running costs for aircraft with the same relative horse-power depend on weight only, other things being equal." Major Mayo did not quite know what this meant; but in any case we were not concerned with aircraft with the same " relative " horse-power. We were examining the effect of varying the horse-power for similar aircraft.

Major Green had touched lightly on the question of fuel and oil. " In a general way," he had said, " the high-powered craft use more fuel and oil per mile." Major Mayo called particular attention to that important expression " per mile," because he wished to refer to it later. Major Green had said that it was impossible to allow for this difference " in a general way," but " fortunately it is not of much importance." The fact was that when he found that some particular factor would not fit into the formula he had wanted to establish, he had said, " Very well, we will ignore it." Then he had tried to relieve his conscience by adding that anyway it was not of much importance.

Pursuing this subject a little further, to see whether this question of fuel and oil was not of much importance, Major Mayo considered two aircraft designed for cruising speeds of 100 and 130 m.p.h. in accordance with Major Green's assumptions. First of all, he said, it was important to clear one's mind on the question whether one was dealing in cost per mile or cost per hour. According to Major Green's own analysis, as shown in Fig. 1, increasing the cruising speed to 130 m.p.h. would mean increasing the cost of fuel and oil *per mile* by 27.4 per cent. This meant increasing the cost of fuel and oil *per hour*, not merely by 27.4 per cent., but by 65 per cent.

Then one had to consider what would be the effect of this increase in cost of fuel and oil on the total operating costs. The proportion of the total costs which was represented by fuel and oil varied, of course, with all sorts of factors, including the price of fuel and oil, the length of stages, the frequency of services, the size of aircraft and the total amount of flying per annum. The larger the total amount of flying, the larger would be the proportion of costs represented by fuel and oil, because the " standing charges " would remain more or less constant while the running costs increased. It might be accepted that, in general, the figure for this proportion would be somewhere in the region of from 25 to 35 per cent., this figure being based on the average prices which had to be paid for fuel and oil over the British Imperial routes.

Assuming the figure to be 25 per cent., the increase in cruising speed to 130 m.p.h. would increase the total costs by 16 per cent. If the figure were 30 per cent., the total costs were increased by 19.5 per cent. And if the figure were 35 per cent., the total costs were increased by 22.7 per cent. A fair average to take for the increase in total costs would be, say, 20 per cent.

The earning capacity per mile was reduced in proportion to the net paying load capacity, *i.e.*, by approximately 8 per cent. The earning capacity per hour (or per annum) would be increased in the ratio $130/100 \times 92/100$, *i.e.*, the earning capacity would be increased by 20 per cent.

Thus, the ratio of earning capacity per annum to total cost per annum would remain the same, the increase in earning capacity being offset by the increase in total costs.

It was seen, however, that Major Green's " Factor of Usefulness," which was intended to represent this ratio of earning capacity to total running costs, was increased from 24.1 to 28.9, which represented an increase of 20 per cent.

Thus by correcting only one item of the running costs Major Green's " Factor of Usefulness " was shown to be entirely misleading. The peak of the curve shown in Fig. 2 had been eliminated simply by taking the cost of fuel and oil into account. If corrections were made also to items 2, 3 and 4, which were dependent on the cruising speed, it would be found that the ratio of earning capacity to total costs would in fact be considerably reduced, and we were back to what was so well known in all forms of transport, namely, that higher speed costs more. Major Mayo pointed out that he had taken only that part of the speed range which (by virtue of Major Green's very arbitrary assumption in regard to the power required for taking-off) was the most favourable to the formula. If he had taken the full range from 100 to 170 m.p.h. it would have shown up the formula in an even more unfavourable light.

There was in fact no short cut to appraising the commercial value of a transport aircraft, such as Major Green had suggested. The " Factor of Usefulness " which he had proposed was not in reality a factor of usefulness at all. It might be of academic interest, but it did not represent the ratio of earning capacity to running costs and was not a criterion of the commercial value of an aircraft. It would be extremely convenient, of course, if some simple formula such as this could be found to represent the commercial value of an aircraft, but unfortunately this was not possible because of the complex nature of the components which made up the total running costs. To obtain anything like the accuracy which was so necessary to the operator, every case must be appraised separately on its own merits, taking into consideration all the numerous factors which varied with the individual proposition. He mentioned, however, that in this respect the aircraft operator was no worse off than the operator of any other form of transport vehicle. There was no form of transport, by land or water, in which the commercial usefulness of the vehicle could be assessed by such a simple process.

Major Mayo said he would not attempt to refer to the remainder of the paper, because the whole paper was based on the formula which was called the " Factor of Usefulness," and nearly all the conclusions reached were dependent on the validity of this formula.

He ventured to say that there was no such thing as an economic cruising speed in the sense that flying at any particular cruising speed could make air transport pay. There was a theoretical economic cruising speed dependent on the aerodynamic qualities of the aircraft, but that speed was generally well below the minimum cruising speed which would be commercially feasible. The speed at which it paid best to fly was dependent on many factors, including the length of stage, the conditions as to wind and the characteristics of the engine. But, above all, the factor which controlled the commercially economic speed was competition. It was competition which forced up cruising speed in all forms of transport, including transport by air, by land and by sea. The transport operator must supply the public with the speed at which it was prepared to travel and for which it was prepared to pay. Imperial Airways were often criticised for the comparatively modest cruising speeds of their aircraft; but it should be remembered that they were one of the few important air transport organisations in the world which had seriously faced up to the problem of making air transport pay. They had, in fact, been flying at the speeds which paid best. It should, however, be remembered that a fleet of aircraft must serve through a reasonably long period of obsolescence, and that in the later stages of that period the performance

of the aircraft was naturally below the improved standard made possible by aerodynamic and constructional advances. As Mr. Woods Humphery had mentioned, it would be commercially feasible to provide for cruising speeds of the order of 130 m.p.h. or perhaps more, in future types of large passenger and mail-carrying aircraft. It was nothing more than a coincidence that this was the speed arrived at by Major Green; the facts were that this considerable increase in cruising speed was largely dictated by the necessity for facing competition in the future, and that it would invitably cost more. It should be pointed out that Major Green's optimum figure of 130 m.p.h. was in reality an arbitrary one, because it was solely determined by the arbitrary assumption he had made in regard to the power required for taking-off—this could be seen at once from the dotted portion of the curve in Fig. 2.

In conclusion, Major Mayo said he did not share Major Green's somewhat pessimistic views, and, for various reasons not referred to in the paper, he believed that the standard of cruising speed required, and the standard which would become commercially feasible, would rise considerably above 130 m.p.h. in the future.

Major GREEN: The results of presenting his paper had exceeded his wildest dreams; he had hoped to be able to get Imperial Airways to come out, and they had done so in a magnificent manner. For a long time they had wanted information as to the cost of running aircraft; they knew reasonably well the cost of petrol (which varied in the different parts of the world) and they knew about how much petrol the various aircraft used, and, now they knew also that it represented from 25 to 35 per cent. of the total cost of operation, it was a comparatively simple matter to find out the cost of operating an aircraft. He was delighted that it was so easy.

With regard to aerodrome charges, he had thought that Imperial Airways had season tickets for aerodromes at which their machines landed very often.

Major MAYO: That was so in places.

Major GREEN: He had thought that that practice was more usual. However, apparently it was a small item, as Major Mayo agreed.

He was sorry that he had not made himself clear with regard to petrol. When he had worked out the figures, neglecting the cost of petrol, he had found that the economic speed was 130 m.p.h. Then he had found that if the machines flew faster, the factor of usefulness would be worse; but he had said that it did not matter very much, because he had already arrived at the answer that it would not be more than 130 m.p.h. Further, he had pointed out that he was merely putting forward a method, and that he was not attempting to give a precise answer. But, unfortunately—or perhaps fortunately, because some very interesting information had been given in the discussion—the paper seemed to have provoked the Consulting Engineer to Imperial Airways, who appeared to think it necessary to defend Imperial Airways for not having flown their machines at 130 m.p.h. That defence was quite unnecessary, however. He had pointed out, when presenting the paper, that having regard to the parasite drag of the machines, they were flying at about the speed he would expect. Also, he had mentioned that the economic speed of the H.P. 42 was about 107 m.p.h., and that the drag, and therefore the economic speed of the Argosy was somewhat worse. He was really trying to persuade Imperial Airways and other operators of the immense importance of reducing the parasite drag, and he still maintained that when they had reduced it they would find that it paid to fly at 130 m.p.h.

He did not think the cost of upkeep varied appreciably with the number of take-offs; there might be some slight effect from that cause. The figure given in the paper for take-off was arbitrary, and he had said that it was, but there were very few aeroplanes flying which had less h.p. per lb. than he had suggested.

Major Green intimated that he would reply to the other criticisms in greater detail in a written communication, and no doubt he would be able to explain more clearly the precise purpose of the paper.

The CHAIRMAN: He felt that Major Green had been rather misunderstood. He had put forward certain figures and certain reasoning which had real scientific interest to the Aeronautical Research Committee. None of the members of that Committee pretended to be experts on economic questions, and that was why they had thought it would be a good thing to have the matter discussed at this meeting—and already the paper had done good in provoking some critical remarks. When Major Green had put forward his proposal he had not pretended that the economics of air transport, or any transport, could be accurately represented by a simple mathematical formula. The question was whether there were any general scientific principles which could serve as a guide in the future. The scientific conclusion at which Major Green had arrived—and which the Chairman wished to have criticised—was practically that there must be a maximum economic cruising speed, *i.e.*, a speed at which there would be the greatest difference between running costs and receipts if a definite amount were charged per ton-mile. He hoped Major Mayo would really deal with this in detail, because it was a point which would affect scientific considerations, and he was very anxious to bring out such points. Major Mayo accepted the view that receipts were roughly proportional to the product of pay load, gross weight and cruising speed; his criticism had been directed towards the cost being proportional to the gross weight, and he had brought forward arguments to show that it was more nearly proportional to cruising speed. Could he put his criticism into more precise form? If one went to the extreme and said that the operating costs were proportional to the cruising speed, one would arrive at the result that there was no optimum cruising speed, and that speed was determined not by facts but by fancies. The question was whether operators could say, from their general experience—extending now over many years—how far costs depended on gross weight and how far on cruising speed. It might be impossible to give that information, but that was the kind of contribution which it was hoped Major Mayo would make in writing, because it affected vitally the lecturial policy underlying the design of commercial aircraft.

The Chairman added that he was glad Major Mayo had made the remarks he had about Imperial Airways, because, inasmuch as there had been some public criticism, it was well to remark that they had gone about their business from the point of view which the taxpayer would heartily commend, namely, that of relieving the taxpayer of his part in the business as soon as possible. That was the right policy.

But the Chairman appealed to all concerned to study this problem seriously, to find out whether it was possible to arrive at some kind of guide for the future. Major Mayo had suggested that there were so many factors that one could not really arrive at a guide, whereas Major Green had said that one could arrive at a guide. As a scientific man he would like the matter put rather more clearly.

Major MAYO: Referring to the Chairman's remarks, he would like to point out that if it were the case that total operating costs were proportional to cruising speed, the cruising speed term thus cancelling out from the numerator and denominator, this would make the " Factor of Usefulness " even more dependent on cruising speed. There would remain only the percentage of paying load, which was reduced very rapidly as the cruising speed increased. The percentage of paying load was really the dominant factor in determining how far it was commercially feasible to go in increasing the cruising speed. He could not, however, agree that total operating costs could be taken as proportional to cruising speed; the relationship was in fact much more complex than that. He added that his point with regard to the formula was not that one could not

analyse the commercial value of an aircraft and get a reliable and accurate picture of it, but that one could not reduce it to a simple formula.

Mr. W. O. MANNING: Referring to the formula, it appeared that if one reduced the percentage pay load by a small amount and increased the cruising speed by a small amount the result would be the same, and on the average a reduction of about .002 per cent. on the pay load was equivalent to an increase of 1 m.p.h. in speed. He asked if that were really the case. Was not increase of speed more important than that? Air transport lived very largely by its speed; but for its higher speed it would have no chance whatever against surface traction. The railways were tackling the question of increasing speed, by the use of Diesel engines, and so on, and it would become necessary for air transport speeds to increase. The average speed of transport by Imperial Airways between the depots in London and in Paris was about 65 m.p.h., and he believed the train speed between the two points was about 40 m.p.h. Probably, if a Channel tunnel were constructed, for that reason alone Imperial Airways would have to increase the speed of air transport very appreciably between London and the Continent.

If this or any other factor of this type were to be useful as a factor of usefulness applying to all aircraft, it should also apply to other forms of transport. No doubt Major Green's ingenuity would enable him to arrive at a factor for a 'bus, a ship or a railway train, and it would be interesting to know whether those concerned with the operation of railway trains, etc., were able as the result of sheer experience to arrive at an economical speed which could be expressed by a formula of the kind put forward in the paper.

Major GREEN: He emphasised that he had not pretended to indicate what was the right speed at which aircraft should fly. His endeavour was to find out the most economic speed of flight, neglecting altogether the convenience of passengers. He did not say that 130 m.p.h. was the right or the wrong speed; but merely that, on his analysis of one particular type of aeroplane, that was the speed at which he had arrived. He was interested in deducing a method rather than giving a result; but if that method were wrong, or too approximate, it was of little value. That was the spirit in which he hoped the paper would be accepted. He could not answer at the moment the detailed criticisms of figures, but he would study those criticisms and do his best to see what were the probable errors which would make the approximation too wide. He personally believed it would be quite permissible to call it a first approximation. But he was not in any way suggesting that he knew the best speed for an aircraft.

Mr. F. HANDLEY PAGE (F.R.Ae.S., Vice-President, Institute of Transport): Proposing a vote of thanks to Major Green, he said that to a certain extent those who had suggested that the paper was entirely fallacious and misleading were wrong, because, after all, Major Green had endeavoured to provide what politicians called a "yard-stick," by which things might be measured—and different politicians used a yard-stick to produce entirely different results.

Apparently parasitic drag was the sole criterion by which aeroplanes were to be compared. It was of no interest to a passenger, sitting in extreme discomfort and having to bear a lot of noise from the engines, to be informed by means of an excellently illustrated pamphlet—he could not be told by word of mouth because he would not be able to hear what was said—that the parasitic drag of the aircraft in which he was travelling was only 25lbs. "per hundred miles," or something of that sort. The passenger was more interested in the degree of comfort he enjoyed during the journey.

If using the yard-stick which Major Green had endeavoured to provide one must compare aircraft of the same type of design. The big biplanes to which Major Green had referred were designed deliberately for a cruising speed of 95 m.p.h.—and at that cruising speed certain fundamental factors in design came

out which settled the proportion of wing area and various other matters. If one were willing to increase the landing speed from about 50 to 80 m.p.h., and if one were willing to tell the passengers that between the point of departure and the destination there was no landing ground in which they could land with safety, then, of course, we should have a different type of aircraft. But if an engine gave out or certain other things happened, the results might be very serious. For the passengers' sake he hoped that the safety factor would not be reduced. Therefore, it was not quite fair to make a comparison in the manner adopted.

There were reasons, beyond those to which Major Mayo had referred, which altered the yard-stick for the low flying speeds and low cruising speeds. One was that of structure weight. One of the big reasons why a passenger-carrying aeroplane had a high percentage of structure weight was the enormous amount of structure to be put into the fuselage. The fuselage was big, a big area had to be covered with skin, and generally it weighed heavy. Such a big fuselage was usually associated with h.p. giving a slow speed, whereas the same h.p., in a machine for high speed, was associated with a relatively small fuselage. If there were two machines of the same weight, and in one case there was more weight in the engine part of it, one would have much more engine but very much less fuselage, and very much less passengers. So that one would have a smaller structure weight in the fuselage, and therefore a smaller structure percentage weight as a whole. It might be that the improvement in the fuselage structure weight was offset by higher factors of safety, but it was hardly fair to compare the two cases because the structure weights were not the same. So that perhaps Major Green had to use a little more experience in stirring up with his yard-stick the pot of aeronautical design. These matters did not work out quite so easily; one wished that they did.

It would be generally agreed that, as Major Green had said, the paper had performed an excellent service, in that it had acted as the piece of cheese to draw the mice who were previously afraid to come out into the open; and they had proved somewhat vociferous.

It had always been a matter of great regret to the Institute of Transport that there were not more papers dealing with civil aviation. Owing to the generosity of the Bristol Company, the Institute had an excellent gold medal to be awarded each year for the best paper on civil aviation. Whilst Mr. Handley Page would not seek to lure people from the Royal Aeronautical Society by the promise of a gold medal, he commended it to the notice of members of the Institute. However, Major Green's paper had been exceedingly provocative, and, judging by the discussion, very valuable in its results. Therefore, the meeting would accord thanks heartily to Major Green, and it was hoped that in written contributions to the discussion there would be a great deal more valuable data.

Mr. C. C. WALKER (De Havilland Aircraft Co., Ltd., *communicated*): The basis on which Major Green estimates the cost of speed is a very unusual one, and, one believes, open to objection.

When considering a series of possible commercial aircraft, the things which are to be kept constant at once suggest themselves. The first is the " load line," or the total weight which can be lifted with the engine power installed. This can very conveniently be fixed by stipulating that all the aeroplanes considered must be able to achieve the same height in the same distance from the start. Other criteria could be used, such as the ability to fly with 50 per cent. of the installed engine power, but, whatever is used, the full load capable of being carried must be considered. In Major Green's series the faster aircraft are not allowed to carry their commercial load, and the slow ones stagger along in an excessively throttled condition. Neither of these would ever be met with, except for accidental reasons, unless an authority issued a decree that wing loadings should be fixed at x lbs. per square foot. (This is not impossible, of course. It has almost happened in the past.)

The other stipulations could be as usual—equal percentage of maximum power to be used for cruising, equal range in miles, etc. On this basis, the landing speed will continually decrease with the decrease of speed. There does not seem to be much objection to this, within reasonable limits, and there are various devices for dealing with the faster end of the scale.

Taken in this way, the weight per horse-power may be anything between 10lbs. or under, and 20lbs., with suitable span and area loadings for an equal screen performance; either of these figures being, of course, rather extreme. The top speeds of such aircraft might range from 120 to 200 m.p.h., and the structure percentages and other characteristics would be widely different.

Looked at in this way, the most economical aircraft speed in the present state of design would be found not to differ very much from that given by Major Green, the curve, however, being flatter.

While admitting that the author has clearly limited his observations to the most economical speed of flight, apart from any other considerations, his interesting paper stimulates discussion of the basis on which the value of transport should be assessed, and it seems to be clear that it is necessary to give speed for its own sake some value. If this were not done, a canal barge would have a " factor of usefulness " about 300 per cent. greater than the best shown by Major Green in his curve, and no faster transport would ever have been wanted. But it is wanted, and the history of transport shows that the " economical speed " is never taken any notice of by anyone. The best speed that people can pay for is always required. Aircraft, being high-speed types of vehicle and in addition using a fuel in which thermal units are expensive, the economical speed question looms rather larger, but is far from dominating.

If it be granted that speed itself has a value, then the obtaining of high speed is useful work done, and must not be described as inefficient transport. The amount of speed which can be afforded by the public is, of course, a matter for the operator to weigh up with all the other requirements, but if once speed is looked upon as useful work it becomes necessary (academically at any rate) to find some way of expressing the efficiency with which the speed is obtained.

It would seem that the only useful work done in any vehicle is the overcoming of the resistance of the pay load in its container. The power necessary will vary as the cube of the speed, so that if a container (say, sufficient for a ton of pay load) is propelled twice as fast with eight times the power, the efficiency is the same in each case if the cost in power of obtaining speed is considered as useful work. Obviously, if speed were given this value, fast aircraft would be more efficient than slow, for the greater the speed the smaller the necessary encumbrances to transport, such as wings, tails, etc.

He had made a curve with what information was available in 1919. The ordinate was " Ton-miles (of pay load) per 10,000 B.T.U.s," with speed for the abscissa. Rail, road and air vehicle results were plotted. If a cube curve is run through the point representing a modern aeroplane on such a chart, it shows the aeroplane to be very superior to anything else, on the basis suggested above.

If Major Green would agree that speed, as well as ton mileage, is a useful commodity, it would be interesting to have his comments on this method of measuring its value. It must have a value or it would not have happened.

Mr. R. M. Clarkson (De Havilland Aircraft Co., Ltd., *communicated*): The investigation is based on the assumption of constant wing loading, and therefore constant landing speed; this, whilst quite rational, does not seem to be such a good basis as that of constant take-off. High speed is generally attained partly at the expense of an increase in landing speed; a high landing speed is one of the sacrifices which one is prepared to make in exchange for high top speed; the landing run can be reduced to a reasonable length by fitting ample wheel brakes, but a safe take-off is essential. In Table I, all the aircraft with

cruising speeds below 140 m.p.h. have the same take-off, all those above 140 m.p.h. have progressively better take-offs, as the speed goes up, due to their lower weights per horse-power. If these machines were loaded up until their take-offs were the same as the slower machines, their factors of usefulness would be increased and the peak of the curve in Fig. 2 might be shifted further towards the high speed end of the scale. It would be interesting to see Fig. 2 plotted on a basis of constant take-off, as well as constant landing speed.

The paper recalls an investigation which the De Havilland Aircraft Company made about a year ago (soon after the advent of the Dragon), in which it was endeavoured to calculate the cost of speed. A constant pay load was assumed (six passengers and luggage), constant range (550 miles), constant take-off (British C. of A. requirement) and the power, leading dimensions, and loadings calculated for a series of aircraft which would cruise at various speeds from 100 to 200 m.p.h., at the same time meeting the above specification. Standing charges and running costs were included, the former being dependent partly on weight and partly on b.h.p., and the latter on b.h.p., first cost was considered to be a combined function of power and weight, piloting costs were also included, and a constant number of flying hours per annum (1,500) assumed. The results appeared in the shape of a curve relating cost in pence per passenger-seat-mile to cruising speed, and it is interesting to note that for cruising speeds below about 140 m.p.h. the cost appeared to be pretty constant at all speeds, whereas above 140 m.p.h. the cost began to rise with increasing steepness. This result is not in bad agreement with Major Green's conclusion.

He was inclined to regard the structure weight of 42 per cent. as being on the high side for any aircraft, except, possibly, large cantilever monoplanes. Percentage structure weight will, of course, increase with size and decrease with loading, and depends upon what one includes in the structure. The figure of 38 per cent. quoted for the D.H. 86 in the paper is incorrect. The structure weight of this aircraft, which was designed to imperial factors of safety, is 30.2 per cent.; this includes controls and instruments, but excludes passenger fittings and engine bearers. This relatively low figure is probably due in part to the biplane structure's comparatively small size compared to that assumed by Major Green, and high loading of the D.H. 86. He estimated that had this machine been a cantilever monoplane, its structure weight would have been about 34 per cent., which would have necessitated a 20 m.p.h. increase in cruising speed in order for it to have the same factor of usefulness as it now has.

Mr. J. L. HODGSON (A.F.R.Ae.S.): The following points seemed to stand out as being worthy of comment:—

(1) The apparent lack of co-operation between designers, such as Major Green and Imperial Airways, both of whom are presumably desirous of cheapening air transport.

(2) The very considerable economy in running costs that was able to be effected by shortening the stages, due to the less weight of fuel that had to be carried. This seemed to indicate the cost of refuelling in the air at, say, 200-mile stages, should be very carefully gone into. The refuelling plane might also be made capable of transferring goods and even passengers, and when attached to a busy aerodrome it might serve more than one plane each time it left the ground.

(3) Major Green's suggestion that there must be an optimum cruising speed seemed fundamentally fallacious.

The most profitable speed for cruising depended entirely upon what the traffic would pay for various speeds—this depended upon such things as comfort, safety, reliability, urgency, and so on. Whether a profit was made depended upon the operating costs at the chosen cruising speed under the actual running conditions. It was only good organisation and design, and low interest charges that would reduce these to a minimum.

The possibility of making a profit at all in the case of air transport depended upon the type of traffic encouraged and handled. In the case of many ocean freights (as where goods had to be stored for some months before use or consumption), cost per ton-mile was the main figure that had to be considered. In such cases there could be no optimum cruising speed, because speed was to all intents and purposes immaterial.

(4) That high speed rail transport seemed likely in future to be able to beat air transport on most well used land routes; and that it was mainly in cross ocean transport (using floating aerodromes), and on little used or difficult land routes that air transport would hold its own.

(5) That the present necessity to make air transport pay was probably only a temporary one; being a condition imposed by a particular and somewhat chaotic economic system. Even under this system, means—such as subsidies—were found to enable air transport to be developed, because for various reasons those in control of credit power (the permission to do and to use things) felt it desirable it should be developed. Yet all the while these controllers of credit power kept both the transport companies and the designers on a string by suggesting that if they did not continually reduce the man hours required to produce a given result their activities would be discontinued altogether.

Additional Reply to Discussion

Mr. Woods Humphery and Major Mayo have criticised the paper in much the same way; I shall reply to both of their remarks at the same time.

The chief criticism of both speakers is that I have not taken into account the cost of fuel. This is a perfectly fair criticism, and I am glad that the point has been emphasised. In my original draft of the paper I intended to put in a correction for the cost of petrol; but until Major Mayo gave me the cost of fuel as a percentage of total operating cost I did not feel justified in doing so. For the convenience of those who may read the paper and not the discussion, I have added a paragraph to the printed paper that was not in the lecture as it was read. My critics, by referring to page 461, will see that their objection is almost justified when petrol costs between 2s. 6d. and 3s. a gallon, and that it is quite justified when the cost is higher. On the other hand, the majority of air transport is run with petrol costing far less than this. At the American price of 11½d. per gallon, the economic speed remains as before and the curve still has a sharp peak.

Mr. Woods Humphery seems to me to be living too much in the past. He should try to live more in the present and future. It is obvious that at any moment Imperial Airways has to work with aircraft that have been designed several years before. My hypothetical aircraft has a drag of 25lbs. per 1,000 weight, at 100 m.ph.., excluding profile and induced drag. Aircraft as good as this have only recently become available, and Mr. Woods Humphery is in no way to blame because the aircraft of his fleet have different characteristics. As an example, I believe that the drag of an H.P. 42 is about 60lbs. per 1,000 weight, and I know that the Argosy is somewhat worse. This is not surprising, as the Argosy was designed about ten years ago. Referring to Fig. 5, it will be seen that the economic speed for these aircraft is well below 110 m.p.h. I feel certain that Mr. Woods Humphery, and even Major Mayo, will be pleasantly surprised to find that Fig. 5 is very near the truth, and that when aircraft are in service with lower parasite drag, so will the economic speed increase. I suggest very seriously that operators should insist on aircraft designers supplying aircraft with a parasite drag at least as low as 25lbs. per 1,000 weight. If they can do this, they will find that operating costs in relation to useful ton miles will be a minimum at 130 m.p.h. air speed. This is particularly fortunate, since it seems that this is the speed that Imperial Airways have chosen for their next batch of aircraft.

I do not pretend to know the real economic speed, as this depends on how much the public are prepared to pay for flying faster than the economic speed of my analysis. Major Mayo is obviously in a better position than I am to estimate the economic speed for Imperial Airways; but I deplore his attitude that the aircraft of our national company should fly as slowly as possible, and only increase their speed to meet the competition of their rivals. His chief criticism is the same as that of Mr. Woods Humphery, that I had neglected the cost of fuel. The addition of Fig. 6 to the paper answers this, and I am obliged to him for the figures he gave me. Although Empire services are rightly the chief concern of Imperial Airways, by far the greater number of miles throughout the world are flown with petrol nearer the lower than the higher figure. When petrol is extremely expensive, Major Mayo can still use the methods I suggest to arrive at the correct economic speed.

Major Mayo's other criticisms do not, I think, affect the result to any extent. He has already agreed that aerodrome charges are usually at a yearly rate, and that therefore these charges do not depend on cruising speed. The upkeep of engines has always been on an hourly basis. The number of starts must have some effect, but it seems to be so small that Imperial Airways engineers neglect it. Engines are, in fact, overhauled after 500 hours' running; not after so many starts. Similarly, dock overhauls of the aircraft depend on hours flown or time only. There ought to be a slight correction for upkeep according to the number of landings, and if Major Mayo will give us some more information on the cost of running repairs as a percentage of total cost, this correction can be made. I feel sure it will not be large enough to make any serious difference.

I entirely disagree with the statement that upkeep of engines has no relation to the gross weight of aircraft. My calculations show that the most economic aircraft is that which has the minimum horse-power for safe take-off and climb. In practice the ratio of horse-power to weight for this is fairly constant. So long as the power used does not exceed 75 per cent. of the nominal power, the cost of upkeep of engines, in my experience, does not vary with the horse-power used. It follows, therefore, that if the horse-power ratio is constant, the cost of upkeep depends on the gross weight. It is quite true that if engines of more than the minimum horse-power are used, then the cost of engine upkeep will adversely affect the usefulness of the aircraft. Again, Major Mayo can help us to assess the difference by giving us an authoritative figure showing the percentage cost of upkeep of engines compared with the total cost of operation.

The wages of the crew depend more on the size of aircraft than anything else. Small aircraft suffer in comparison with large aircraft, but this has little to do with the determination of the economic speed, except that it will be a shade higher for small aircraft than for large air liners.

Major Mayo's final remark seemed to me to be contradictory. He says he hopes that speeds above 130 m.p.h. will become commercially feasible, and he accuses me of pessimism. I not only hope that speeds far in excess of 130 m.p.h. will become usual, but I am quite certain that they will. We only differ in our estimation of how much it will cost to fly faster. Major Mayo is surely the pessimist as he believes that with the state of the art as it is, the economic speed is 100 m.p.h. or less. I am the reasoned optimist, since I put the speed at 130 m.p.h. at ground level and considerably more at greater heights.

In reply to Mr. Manning, I can only repeat that the economic speed that takes no account of the value of flying fast is not intended to be the best speed for flight. I do not say that 130 m.p.h. is the right or wrong speed; but merely that on my analysis on one particular type of aeroplane this is the speed which gives the greatest economy per ton mile of useful load. I have endeavoured to give a method rather than to produce a result; if the method is too approximate, then it is of little value. I still believe that it is a good first approximation and that it can be improved as more information is available.

In reply to Mr. Walker, I certainly agree with him that speed itself has a value, but I have no means of expressing this in figures. I also agree that if higher landing speeds are permissible, then there will be some saving in structure weight. This will tend to make the cost of flying faster less pronounced than is shown in the diagrams. It is unlikely to alter the optimum point, and it will in fact counteract to some extent the increase due to cost of fuel as shown in Fig. 6.

Mr. Walker is scarcely correct in saying that the slower aircraft I have specified will stagger along with engines excessively throttled; this is rather the state of affairs advocated by Major Mayo. I have assumed that 75 per cent. of the normal power of the engine is used at the speed that I consider to be the most economical.

In reply to Mr. Clarkson, I am interested to know that using an entirely different method of analysis, he finds that the cost of operating per passenger-seat-mile is fairly constant up to 140 m.p.h., and that it rises with increasing steepness after that speed. This is not very different from the conclusions in this paper. Might I suggest that Mr. Clarkson publishes a detailed description of his method?

I do not think it is quite fair to increase the landing speeds of higher powered aircraft by arranging for a constant take-off. If this is justifiable, I agree with Mr. Clarkson that the curves will be flatter and that the factor of usefulness will be raised for higher speeds. I congratulate the de Havilland Company on the low structure weight of the D.H. 86. I hope it will not go up with use, as always seems to happen after the sample aircraft has been tested.

Mr. Hodgson's remarks are rather outside the scope of my analysis. I agree that by neglecting the convenience of the passengers I have ignored a factor of vital importance. As I have already stated, I cannot assess the value of increased speed; all I have attempted to do is to devise a method of calculating how much extra it will cost to fly faster than an optimum speed.

Finally, I wish to thank those who have added to the value of the paper by their criticisms and suggestions. They seem fairly evenly divided into those who think I have favoured the faster aircraft at the expense of the slower, and vice versa. I still believe the method I have described will be of help to the aircraft designer in particular, and that much of it can be accepted safely by the aircraft operator. As statistics of the world's air lines become available the method can be tested and improved. I hope it will be studied by all those who are interested in civil aviation, and that they will help by publishing as much information as they can which can be used to check and improve the method.

A METHOD OF COMPARING THE PERFORMANCES OF COMMERCIAL AIRCRAFT

BY

M. LANGLEY, A.M.I.AE.E., A.M.INST.N.A.

Major Green in his paper has given prominence to a subject which is now becoming of wide interest and great commercial importance. A method of assessing the economic value of speed is very desirable and Major Green has attempted to do this by means of an index figure.

I would like to put forward a method which, whilst it does not provide a datum or index figure, offers a ready method of comparing two or more machines, taking into account those features of the aircraft which are of economic importance. It must be accepted that the geographical and political features of different routes, time-tables, and other such extra-to-aircraft items could be included in any method of comparison without the use of an empiric formula, the relative importance of whose terms would be largely a matter of opinion. Further, this method is based not on subsidy earning but profit earning capacity.

Suppose that an air transport operator is offered two very different types of equipment for the same route. They may be of different size, speed, pay load, range, and engine power, etc. In fact, there are so many variables involved in the machine itself that the relative importance of each feature becomes obscure. The method which is graphical, is worked as follows:—The gross weight of each machine is divided by its *cruising* h.p. and this is set up as a vertical ordinate to some scale. That portion of the gross weight which consists of tare weight and crew is also divided by the cruising h.p. and marked off on the same scale. The difference is the disposable load per cruising h.p.

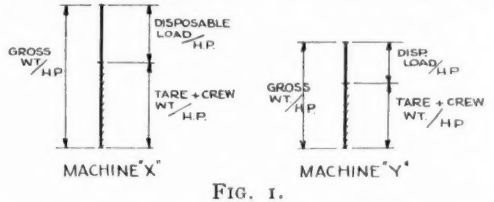


FIG. 1.

The disposable load may be any mixture of pay load or fuel load, depending on the range. If it is all assumed to be fuel load and the consumption is known, the ultimate range is at once calculable. This is plotted to the right of each diagram.

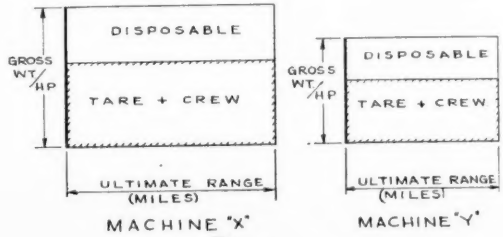


FIG. 2.

If it is assumed that tankage per lb. of fuel and furnishing per pound of pay load weigh approximately the same, and if, further, that fuel consumption per mile is the same throughout the range, then a diagonal line may be drawn across the upper part of the diagram, dividing it into pay load and fuel load.

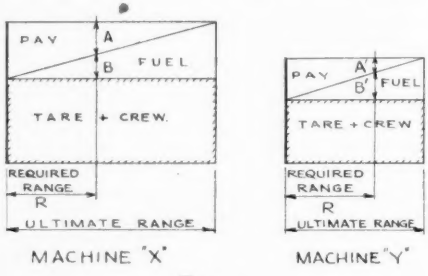
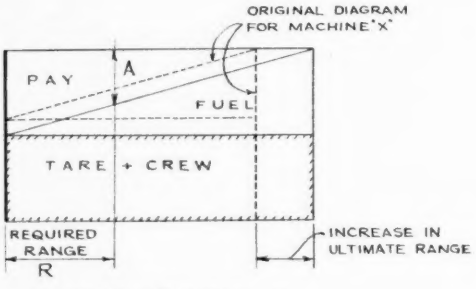


FIG. 3.

If these approximations are not accepted as being sufficiently correct, it is simple to adjust the diagram in accordance with the refinements introduced. If verticals are now drawn across each diagram at the required range one can see at a glance how both pay load/h.p. (A and A^1) and fuel load/h.p. (B and B^1) compare.

Several interesting points now arise. If at any particular range, R, the fuel load per h.p. is represented by B (or B^1), then B (or B^1)/R represents the fuel load per h.p. mile. Since fuel load in lbs. bears a constant relationship to gallons of fuel, this fraction is a measure of gallons/h.p./mile. It is, moreover, the tangent of the angle of slope of the diagonal. The flatter the slope, the more efficient the aeroplane.

Consider how alterations in design affect the diagram. If the tare weight or crew weight is reduced whilst keeping the same gross weight, the earning capacity of the machine is increased. This appears at once in the diagram.



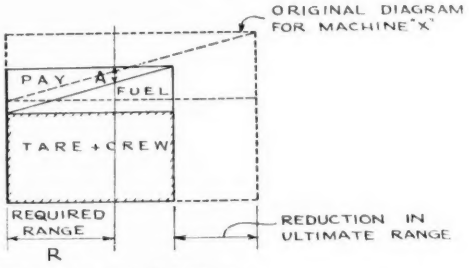
EFFECT OF REDUCTION IN TARE + CREW WEIGHT.

FIG. 4.

The value of gallons/h.p./mile is unaltered; in other words, the slope of the diagonal remains the same. The ultimate range is increased, and with it the value of A or pay load per h.p. at the required range.

If the cruising speed is increased by the fitting of larger and more powerful engines, other things remaining unaltered, both the tare and crew wt./h.p. and the gross wt./h.p. are reduced. At the same time the ultimate range is

less owing to the greater consumption. Another way of expressing this is to say that both pay load and pay load/h.p. are reduced whilst the running expenses (which are a function of the gallons/h.p./mile) remain the same or are increased.

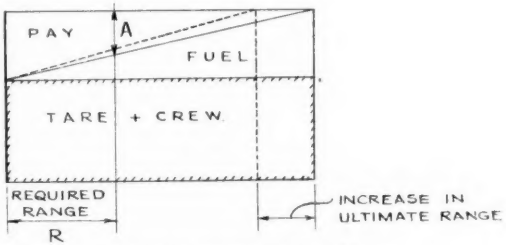


EFFECT OF FITTING BIGGER ENGINES.

FIG. 5.

If, on the other hand, the cruising speed is increased by reducing the parasite drag, the effect is beneficial. The fuel consumption being the same, and consequently the endurance, the higher cruising speed will convert this endurance into a greater range. At any given working range the value of gallons/h.p./mile is reduced and the pay load inceased. This illustrates very clearly that cleanliness is profit earning. But if the parasite drag had been cut down at the expense of an increase in structure weight (*e.g.*, the substitution of a heavy but clean cantilever wing for a light but unsightly biplane structure) the sloping line assesses the alteration at its true worth.

The slope of the diagonal is therefore a measure of the L/D ratio of the machine. But it is also a measure of the specific fuel consumption of the engine. If a highly efficient engine is used, the slope is reduced. The commercial value of a heavy compression ignition engine with a small specific fuel consumption is at once apparent for any particular range.



EFFECT OF REDUCING DRAG OR SPECIFIC FUEL CONSUMPTION

FIG. 6.

This, of course, may not be strictly true if the maintenance charges of petrol and heavy oil engines are not the same; or, putting it differently, if the running costs are not proportional to gallons/h.p./mile for the different types of power plant.

Provided that its limitations are understood the diagrammatic method would seem to offer a solution of the operator's difficulties when faced with the selection of equipment, each type of which is backed by a different desirable feature. For the designer it offers a method of comparing such rival claims as those of low structure weight and high power loading. In this connection it illustrates the underlying reason of the recent tendency to use higher power loadings with V.P. propellers. The limit to which one may push the power loading must still be decided by the geography of the particular route under consideration.

(Correspondence on this paper is invited.—EDITOR.)

WINTER LANDING GEAR

BY

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Snow

Snow falls in a great variety of forms, depending on a large number of conditions affecting the crystallisation of the moisture in the atmosphere. The forms may even vary from place to place or from time to time in one storm.

The character of snow as a medium for transportation depends not only on the form of its constituent crystals, but on the nature of the ground on which they fall, the depth of the total covering, the previous history of the underlying layers, and of course on the history of the last fall and the atmospheric temperature of the moment. Considering the characteristics for the purpose of aircraft operation, it is sufficient to make the broad classifications shown in Table I (page 504).

The dry snows occur when the atmospheric temperature is well below the freezing point, the powdery kind coming usually at lower temperatures than the fluffy. The granular snow is often associated with low temperature and high winds, that is, blizzard weather.

Wet, soft and fluffy snow is produced at temperatures close to the freezing point, and, if the atmospheric temperature near the ground is above the freezing point, it may turn to slush.

If dry snow lies on ice, it will not adhere, but becomes easily displaced and consequently skiis, sleds, toboggans, etc., can slide sideways almost as easily as they do forwards, and steering becomes difficult. The situation improves with the depth of dry snow covering by virtue of the increase in mass of snow which has to be displaced in sideways movement.

Dry snow will always drift in a wind, and in unsheltered places where the wind has a wide sweep, there often results a series of hard ridges similar to sand dunes. The windward slope of these ridges is gradual, but the down wind face is abrupt, and the actual crest is often overhanging.

Ridges about twelve feet from crest to crest and eighteen inches to two feet high are common on the smaller expanses while even higher ridges are frequently encountered in the larger expanses of the northern regions. The wind exerts a packing and polishing action which makes the snow extremely hard and shiny. Aircraft which have to land and take-off from such a surface as this, facing the steep sides of the ridges, are subjected to a severe buffeting.

Owing to the heat insulating properties of snow, a quite thin layer of dry snow may prevent boggy, soft ground or slush from freezing and becoming hard. If the snow is of insufficient depth to prevent penetration of skiis, conditions become such as to make an aeroplane take-off extremely difficult, if not impossible. Where the slush has been exposed by the skiis displacing the snow, it will freeze, and in this way, a runway may be laboriously made, but at the same time, there is always present the disadvantage of slush freezing on to the bottom of the ski, and this is often very difficult to remove, as it necessitates jacking up the aircraft to remove the ski and clean it.

If the precipitation of snow is very heavy in the late autumn or early winter, before the ice on lakes and rivers has had time to thicken, the weight will break the ice and sink it, allowing water to attack the bottom layers of snow and form slush. As more snow falls the sinking process continues and more and more slush is formed, the original thickness of ice never growing any greater, and in fact sometimes growing less, due to solution. As the lakes and big rivers of Northern Canada provide the aerodromes for winter aviation and the highways for the tractor drawn trains of supplies, it can easily be understood that early and continuous snowfall may be regarded as a calamity. Thaw, accompanied by heavy rainfall, is a godsend as the formation of a new layer of ice is thus permitted.

Dry snow on hard packed snow provides an excellent medium for landing and taking off, but a new fall on bare, hard ground is often insufficient to protect the ski bottom from contact with frozen earth and pebbles, especially where the snow has drifted from the higher spots. There is thus a constant risk of scoring the ski bottoms in early winter.

Crusted snow, whether overlaid or not, is frequently a source of difficulty, as the crust is seldom sufficiently strong to support an aeroplane at rest or moving slowly. When a ski breaks through the crust, there is considerable resistance to forward motion, and turning is almost impossible. Tail skiis being more heavily loaded than main skiis usually break through first with consequent damage to fuselage and tail surfaces. If the main skiis break through a thin crust the slipstream will pick up small chunks of the ice and drive them right through fabric surfaces.

Wet, soft and fluffy snow offers very considerable resistance to forward motion for two reasons. The coefficient of friction is high, and the snow tends to pack into a heavy mass in front of the skiis instead of being ploughed aside in a feathery spray like dry snow. In this respect, it is worse than really wet slush, which behaves more like a fluid and gives way to some extent to the passage of a ski.

A difficult surface condition arises as follows:—The snow on an aerodrome having become slushy owing to a rise in temperature, and having become ploughed into ridges and furrows by ski and tail ski, the atmospheric temperature drops and the slushy snow freezes. The hard ruts and ridges are very severe on any kind of landing gear, and particularly on tail skids and skiis.

A similar condition has been observed on comparatively unused lakes where slush underlies the snow. High winds displace the snow in drifts exposing the slush in patches which subsequently freeze, forming hard ridges impossible to detect after the next snowfall.

Another bad surface is created by rain on snow, followed by frost and then a further snowfall. The aerodrome then becomes covered with patches of glare ice and drifted snow. It is not safe to use wheels on account of the snow drifts and directional control on skiis is seriously impaired.

Dry granular snow at a low temperature has a very high coefficient of friction, sufficient in recorded instances to prevent take off. It is presumed that its behaviour is somewhat similar to that of sand and that the low temperature prevents the melting of the top layers under the pressure of the skiis.

Loading

Scientific information about the supporting power of snow under load and its resistance to the passage of different kinds of ski is unfortunately very meagre, and there does not exist, to the writer's knowledge, a record of any really extensive research on the subject, and indeed such research must necessarily take a long time, because the various snow conditions, a few of which have been described, do not repeat themselves with any regularity, and whole winters may pass without some conditions appearing at all. In over eleven years'

experience, the writer has not seen a winter which has not produced something new. It is not economically possible to create conditions artificially, nor can the work be done in a small space, as repetition tests cannot be made on snow that has once been used. The logical solution for research purposes is to provide an aeroplane capable of carrying a wide range of loads and with a dynamometer incorporated in the undercarriage and tail ski. This equipment could then be flown from place to place in search of the widest variations of conditions considered to be necessary. The load could consist of different kinds of skiis to enhance the variability as well as the mobility of the research equipment.

Fortunately for the engineer, an exact knowledge of the coefficient of resistance of the different kinds of snow is not absolutely necessary in order to deal with present day practical problems. The thrust available is determined by flight performance requirement, and the loading of the skiis is necessarily a matter of compromise with aerodynamic, structural and weight considerations on one side, and facility of take-off on the other. The designer must set himself a limit of conditions beyond which it would be unreasonable to expect the aircraft to take off. This limit may depend on a number of factors such as the prevailing climate and the nature of the terrain to be flown over; the frequency of emergency landing grounds, and the urgency of the service. In Canada, skiis are usually larger than necessary for aerodrome use, the extra size being dictated by a desire to provide for capability to take-off after a forced landing on unpacked snow, such as may be found on the surface of frozen lakes.

The specific loading of skiis depends to a great extent on, and varies as an inverse function of, the power loading of the aircraft. Thus an aircraft with a high power loading requires a light specific loading on the ski, and vice-versa. In Canada, the limits are roughly from 140lbs. per square foot for heavily power loaded commercial and private aircraft to 200lbs. per square foot for single-seater fighters and high performance aircraft generally. The wing loading must have some effect, but it is not nearly as important as the power loading, as the main difficulty is in the acceleration up to the first twenty miles an hour or so. Skiis on snow seem to act in a somewhat similar manner to hydroplanes on water, that is to say, that once a certain speed is reached, they seem to " plane," or at any rate, they do not penetrate so far beneath the surface.

Shape of Skiis

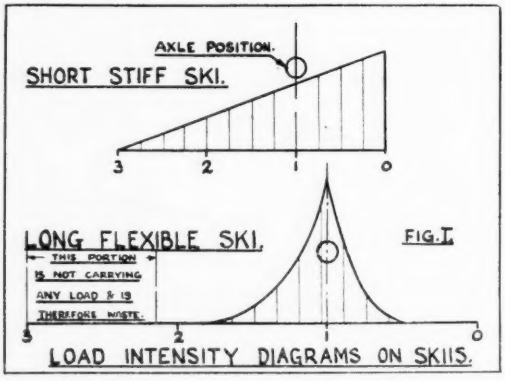
There is little agreement on the ideal shape for a ski and here again compromise enters largely. There are some who claim that a long, narrow ski offers so much less resistance than a short, broad one, that they are prepared to make many sacrifices in other directions in order to retain the alleged low resistance feature. The writer is of the opinion that accurate research alone will enable standardisation to be reached in this important respect.

The factors which affect the length of skiis are as follows:—

(*a*) Reasonable simplicity of construction.
(*b*) Interference with other parts of the aircraft.
(*c*) Resistance to forward motion on the surface.
(*d*) Twisting loads on the undercarriage, due to turning, etc.

An unreasonable length will tend towards extravagance in weight as, for a given average intensity of loading, the bending moment increases in direct proportion to the length. Again, a flexible ski would have to be made thick enough to prevent sagging caused by its own weight, or undue deflection, when under load. If the ski bends too freely, the intensity of load under the axle will be very high compared to that at regions further forward, and consequently the material is not being used in an economical manner. Better results would be obtained from a stiffer ski of smaller area.

The longitudinal load intensity diagrams for a very flexible and a very stiff ski are something like the curves in Fig. 1.



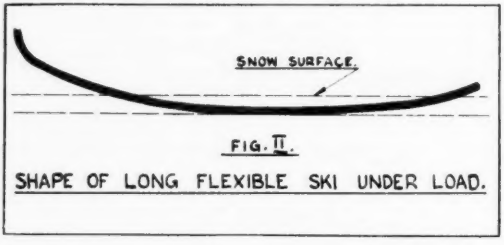
LOAD INTENSITY DIAGRAMS ON SKIIS.

An unreasonable width, on the other hand, will lead to difficulties in distributing the load across the ski and will again lead to extravagant disposition of material.

From a purely practical point of view, it is economical to avoid splicing of planks. There is a larger percentage of specification lumber in short lengths than in long lengths in any given parcel, and it is also economical to avoid built up trusses as far as possible, when simple beams can be made to do the work for nearly the same weight.

It sometimes happens that a ski may foul some other portion of the aircraft. It is desirable to avoid, if possible, the intersection of the airscrew disc with the disc of rotation of the ski. If this is not possible, extra precautions are necessary in order to preclude entirely the possibility of the airscrew striking the ski.

Ideally speaking, a long narrow ski will have less resistance to forward motion than a broad one, for the simple reason that less new surface is being attacked in a given time at any given speed. One can well imagine that a body of troops could move in column through thick grass with less total expenditure of energy than an equally large body moving in line. The rear sections of the column would have a well prepared track trampled for them. The analogy breaks down, however, when one considers a very long narrow ski of great flexibility. Such a ski would take a shape somewhat as in Fig. 2.



SHAPE OF LONG FLEXIBLE SKI UNDER LOAD.

As mentioned before, the intensity of loading under the axle would be very high, and consequently the flexibility of the ski will permit a very deep penetration of the snow, so that in effect, every particle of the ski bottom from the leading point of contact to axle pedestal would be breaking new snow. The

tail portion only would have the entire trail broken for it. There must be for any given condition of snow and loading an ideal ratio of length to width, considering low resistance as the only criterion. This ratio has not been established, but the writer is of the opinion that it is higher than that in general use, compromise having been forced by other considerations—those which follow in particular.

When an aeroplane on skiis is turned, the original impulse is at the tail, and is transmitted through the body down through the members of the undercarriage to the ski, and the resistance to turning offered by the last named is, for a given overall loading, solely a function of the length. This consideration, more than any other, places a practical limit on the length of skiis, not only from the desire to retain directional manœuvrability, but also to guard against excessive twisting loads on the undercarriage.

It is quite probable that the severest loads are inflicted when the aeroplane is being turned by the ground handling crew. It is quite a common practice to lift the tail of an aircraft and heave sideways till the skiis begin to turn. If the skiis are frozen down the results may be damage which the original undercarriage designer certainly never foresaw.

Certain undercarriages of the split axle type have such a geometry that vertical movement of the axle is always accompanied by a component rotation about a vertical axis or a fore and aft axis or about both. The result is that, on landing the ski track widens and the skiis themselves may toe in or splay out, causing loads on the undercarriage very similar to those caused by turning. The loads imposed may be very severe and the writer knows of at least one instance when they caused failure of an entire undercarriage.

" Straight through " axles must be made very stiff for winter work, as any deflection caused by the drag of the skiis tends to increase that drag and conditions are rapidly aggravated until failure occurs.

The Department of National Defence of Canada has found that a ratio of length to breadth of approximately $4\frac{1}{2} : 1$ affords a satisfactory compromise which the experience of a number of years' operation has done nothing to discredit.

Finally, in the discussion of ski shapes, we come to the debatable merits of flexibility versus rigidity in a ski. The argument can never be properly settled without research, but there are some points which it might be worth while to mention as offering guidance on the basis of pure reasoning. The proponents of the flexible ski in Canada point to the established usage of toboggans, and argue that the usage would not have survived for generations if a rigidly constructed toboggan had been found to be better. This argument may have some justification, but it does not take into consideration the fact that the load on a toboggan is distributed throughout its length, whereas that on an aeroplane ski is concentrated at the axle and distributed from there by means of a pedestal. The writer has heard it stated that a flexible ski will conform to any uneven configurations in the ground. A little thought will show that unless the ski is almost infinitely flexible, it cannot do this when loaded conventionally. For example, consider that a slight projection in the ground exists about half way between the pedestal and the tip. What force, other than that of gravity, is there to make the fore part of the ski conform to the forward downward slope of the projection?

A flexible ski has the advantage that it probably absorbs more of the impact caused by striking a rise in the ground, and in deep snow its upward deflection causes a more gradual entry which may result in a sort of planing action rather than a ploughing action. The " planing " effect, however, can be achieved with a rigid ski by proper positioning of the pedestal.

The desired cross section of the bottom surface has a great deal to do with the matter of rigidity. In order to reduce the side loads and the torque in a horizontal plane caused by cross wind landings, or by turning, it is desirable

to bevel the edges of a ski, so that in any sideways motion the edge will tend to ride up rather than dig in.

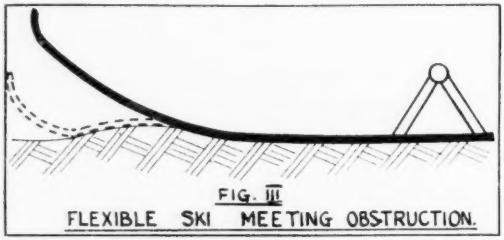


FIG. III
FLEXIBLE SKI MEETING OBSTRUCTION.

If this bevel is to have any appreciable effect, the cross section must have a certain amount of depth, and this dimension is always in opposition to flexibility. Again, in order to facilitate unsticking when the skiis have become frozen, or half frozen, to the underlying snow, most ski bottoms are built to have at least two different levels. This may be effected by adding two or three moderately wide slats on the otherwise flat bottom surface, or by building the bottom with the edge plank turned up at an angle.

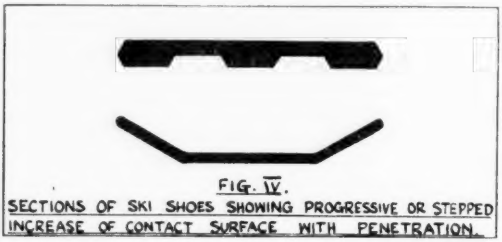


FIG. IV.
SECTIONS OF SKI SHOES SHOWING PROGRESSIVE OR STEPPED INCREASE OF CONTACT SURFACE WITH PENETRATION.

On hard surfaces the effect of this alteration of level across the ski bottom is to reduce the friction, as there is less material in actual bearing contact.

The second form of bottom is favoured by the Department of National Defence in Canada because it looks after the bevelled edge problem as well. This form necessarily produces a rigid ski.

Methods of Construction—Skiis

The simplest ski for small aircraft consists of a single plank bent up at the ends and fitted with a pair of cross battens to accommodate the legs of the pedestal. As a refinement, the plank can be tapered in thickness towards the ends, then frequently a cross batten is added at the tip and at the rear end to prevent splits and to take the anchorage for trimming cables (Fig. 5). Sometimes the reverse process occurs and the splits appear first and the cross battens are added as a method of repair, and this leads us directly to the next stage in complication of construction, namely, a number of planks laid parallel, turned up at the ends and held together by battens. It is only a short step from this to the ski with the edge planks turned up to form a shallow trough-shaped section. Such a ski will have a lot of hollow spaces on top which might collect snow and slush, so the next step is to add a thin cover over the battens and we reach the ski standardised by the Department of National Defence in Canada for the past two or three years. This form of construction is really very simple. The joints between the planks need not be any better than can be obtained with

a saw cut, and the ski can be made to rely entirely on bolted or screwed connections, thus facilitating repair or replacement of damaged planks (Fig. 6).

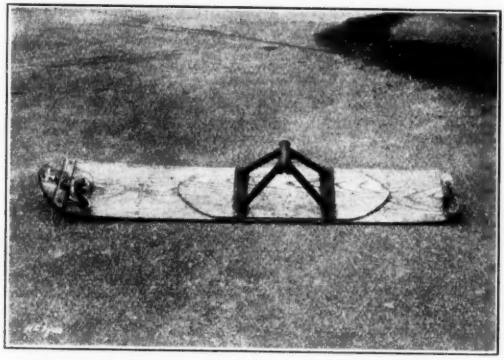


FIG. 5.

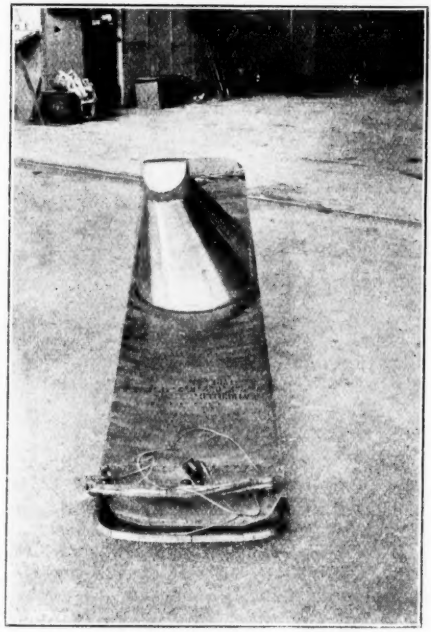


FIG. 6.

The flexible type of ski for the larger aircraft is usually built up of a number of laminations fastened together by copper rivets, the joints in any one layer being covered by the solid wood of the next layer. Successive laminations are discontinued as the ends of the ski are approached. Two or three slats a few inches wide are fastened on the under side. This type of ski is easy to construct,

but requires a very large number of fastenings, the weight of which becomes appreciable (Fig. 7).

There have been a number of examples of what might be called " float-shaped " skiis constructed. These range all the way from an ordinary ski with the pedestal faired in by canvas over a wooden or metal frame to a regular float construction with load bearing frames, which themselves comprise the pedestal and a skin which is relied upon to take the bending (Figs. 8, 9 and 10).

These skiis are necessarily expensive as compared with the simpler type, and as a matter of fact, for aircraft of medium performance—which classification comprises nearly all commercial types—the difference in drag is hardly noticeable,

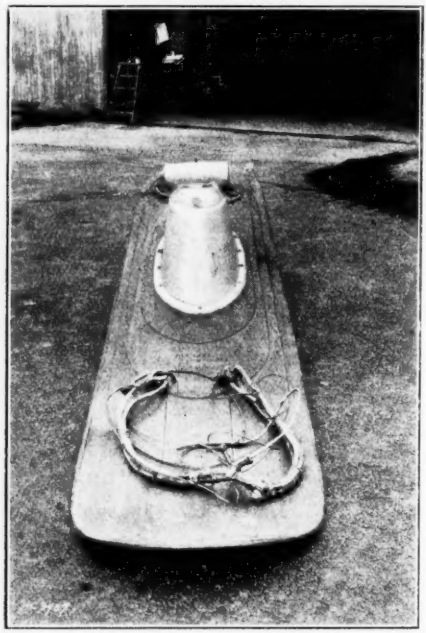


FIG. 7.

as a percentage of the total drag, and therefore the extra expenditure is not justified. For anything that performs at over 150 m.p.h., however, it is felt that a strong effort towards streamlining is justifiable. A float-shaped ski is good in slush as it does not pick up a heavy load of slush, which not only impairs performance by reason of its weight but also freezes hard and provides endless trouble to remove after the succeeding landing.

There is little advantage in weight to be gained by the stressed skin type of construction, for it has been found by bitter experience that the bottom of a ski must possess a certain amount of " body " in order to resist the impacts on hard snow and the scraping action of small stones, cinders and frozen earth which sometimes protrude through the surface on busy airports. The necessity for this body means that the shoe can usually be made to have all the strength required. Any fairing on the upper side should be made as light as possible consistent with practical considerations, not the least of which is the propensity which is evinced by most people for standing on the deck.

Obviously, the material which possesses " body " and at the same time a good strength, is wood, and the writer is of the opinion that wood will continue to be used for ski shoes indefinitely. Ash is probably the commonest species used on account of its relatively light weight compared to its strength. Hickory might be used, but is heavier and more costly. In laminated skiis, spruce or

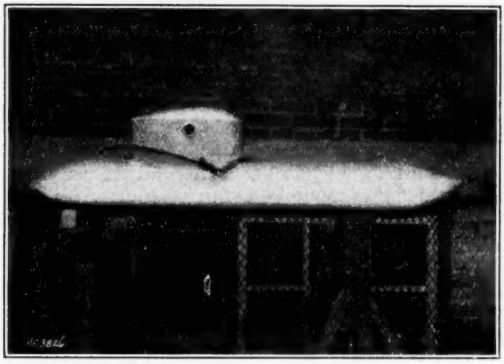


FIG. 8.

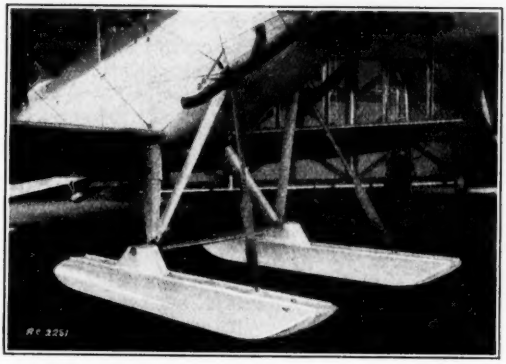


FIG. 9.

FIG. 10.

some other soft wood could be used for the upper layers, but one must guard against wide variations in shrinkage properties of neighbouring laminations. It is not considered necessary to use wood of faultless grade, such as is insisted upon for structural members of the air frame, and consequently the sources of supply are not restricted.

Nearly all skiis in Canada are soled with sheet metal, either wholly or partially, and this metal serves two distinct purposes. Firstly and obviously, it protects the wood from damage caused by stones, ice and other hard particles. A plain wood ski would only last a very short time in some districts, especially at busy airports where there are buildings and hangars, as the sun's warmth reflected from the buildings melts the snow round about and the covering gets thin, exposing cinders, gravel, concrete, or whatever material is used to pave the apron. The second function is to combat the tendency to freeze down the skiis. Moisture will penetrate a wood surface, and when the temperature drops, the ice particles are extremely tenacious and difficult to scrape off. A metal sole, though by no means free from trouble, is less liable to ice up than wood, and when it does, it can be cleaned off with more ease and less liability to damage. By repute, brass is the best material for anti-sticking, but strong aluminium alloy is little, if at all, inferior in this property, and its use is recommended as a thicker sole may be had for the same weight, making a more durable job. The sole may be fastened on by means of ordinary countersunk head wood screws, or by rivets, the screws being preferable as they are more easily removed for replacement purposes. The metal is dished at each hole to form a countersink for the screw head and the spacing depends upon the nature and thickness of the material used for soleing. Joints may be made in the sole, and it has been found that lap joints are the most satisfactory, provided that precautions are taken not to drag aircraft backwards, nor to turn except during forward motion.

As it is a very laborious proceeding to remove the sole piece, arrangements should be made so that all bolts used for fastening fittings on the upper surface should be prevented from turning so that replacements can be made from above by merely unscrewing the holding down nuts.

The edges of skiis are subject to severe scoring in crusty snow, and it is advisable to protect these with metal sheathing which can be secured with wood screws.

There is no advantage to be gained by the use of special aircraft bolts for the fastenings, except in the vital places, and economy can be effected by using ordinary commercial hardware. In the Canadian Government ski a fairly large number of bolts is used for fastening the cross battens to the planks and carriage bolts are used for this purpose.

In assembling a ski, the wood should be put together quite damp as it will frequently be very wet in service, and it is desirable to avoid disruption of the fastenings through swelling in a structure that was tightly fitted when dry.

When bending planks at both ends it often happens that one end may be satisfactory while the other end splits. In the construction consisting of several planks and cross battens, there is no objection to a certain proportion of spliced planks, and so there is no need to throw away a good bend provided that there is enough plank left to effect a good splice where it can be secured by a batten.

Pedestals

Although the construction of special ski undercarriages might be worth while for aircraft operating on regular schedules over snow-covered country, it is the most common practice to make use of the wheel undercarriage and to attach the ski to the aeroplane through the medium of a pedestal which is secured in the place of the wheel. The height of the pedestal is usually arranged to give the same airscrew ground clearance as was available with the wheel.

Pedestals may be divided into two types, viz., shock absorbing and non-shock absorbing, and although the advantages of the former are becoming more and more apparent, the latter are still in the vast majority. It must be remembered that when the wheels of an aircraft are removed, the springing characteristics of the undercarriage as a whole are considerably reduced. At the same time, as has been explained in the leading paragraphs of this paper, the surface

conditions are often very bad, and additional, rather than less shock absorbing, is required.

It is fairly safe to say that the use of skiis is more severe on undercarriages and fuselages than that of either wheels or floats.

There are many forms of non-shock absorbing pedestals and the earliest, to the writer's knowledge, consisted of a pyramid of wooden struts fastened together by means of metal plates and suitably strengthened against sideways collapse by means of cross bracing wires (Fig. 11).

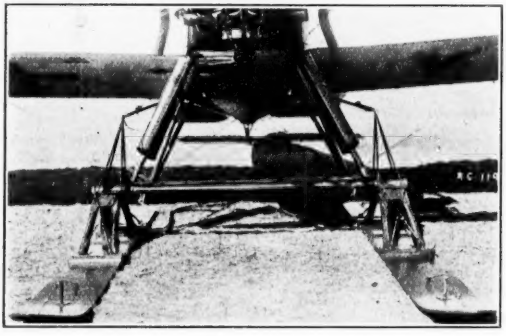


FIG. 11.

Fundamentally, the same form of pedestal can be produced in metal tube and persists to this day. It is cheap, simple and sturdy (Fig. 5).

The metal form is sometimes extended into a regular truss which can be faired in by a canvas cover (Fig. 12).

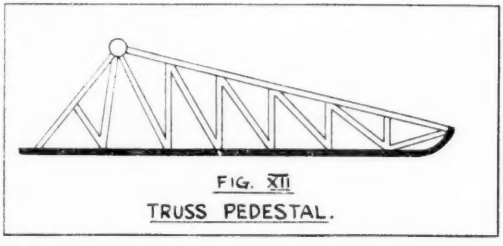


FIG. XII
TRUSS PEDESTAL.

In an attempt to produce a light pedestal having a smooth appearance and a reduced air resistance, a shape rather like an inverted coal scuttle was produced. This pedestal carries load in the skin and also by means of diaphragms suitably placed inside. The later models proved to be quite serviceable, but they were rather expensive to manufacture in limited quantities and were finally abandoned by the R.C.A.F. in favour of shock absorbing types (Fig. 6).

The hole through the top of the pedestal is made large enough to accommodate the largest axle corresponding to the maximum weight for which the pedestal is designed. Bushes were used to look after smaller aircraft within the range of suitability.

The unsymmetrical construction of the pedestal is noticeable. The reason for this was to get the ski well under the supporting members of the axle and thus reduce bending moments. There is, however, a distinct disadvantage from the point of view of economy in having a "[illegible]ded" structure.

Several similar forms of pedestal have appeared, one of which is still in common use and is constructed of wood laminations hollowed out inside for lightness, while others are constructed of welded steel or even light alloy castings. The wooden ones come heavy and have the disadvantage of being subject to unequal shrinkage and consequent season checking (Fig. 7).

A very neat form of pedestal was produced some years ago by the Curtiss Reid Aircraft, Ltd., of Montreal. In front view it looks like a vee, and in side view like an inverted vee, and it is articulated to the ski shoe so that the latter is free to rotate about a fore and aft axis, a restraining spring and limit stops being provided. This freedom to rotate allows the ski to bear all over, even though one ski may be at a higher level than the other. It facilitates turning during ground manœuvres and is especially useful for split undercarriage types (Fig. 13).

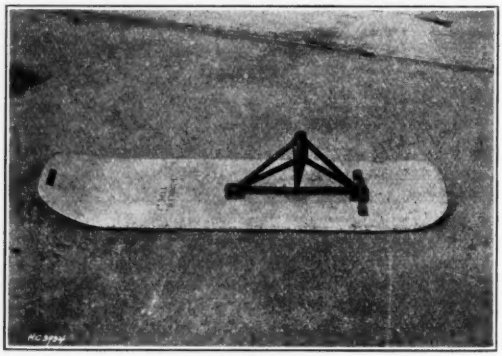


FIG. 13.

There are three models of shock absorbing pedestal which have been in fairly common use in Canada. One type consists of a steel tubular framework which carries and guides a bronze sliding block bored for the axle. This block is suspended from the top of the framework by rubber shock absorbing rings. Another type consists of an inverted coal scuttle-shaped light alloy casting embodying long vertical slots for the axle, which again is suspended from the top of the pedestal by rubber cord. Both these types suffer from the disadvantage that it is possible for them to become jammed quite easily with frozen slush or packed snow. The hollow casting with a long slot is particularly likely to collect driven snow inside, which will always mean extra weight even if it does not stop the action. Rubber cord has also the drawback that its elastic properties are adversely affected by cold and its use for winter flying should be avoided where possible, especially if it is subjected to continuous load as it would be in a pedestal (Fig. 14).

The type of pedestal used by the R.C.A.F. is known as the "Oildraulic Pedestal," which consists of a robust cast frame, the lower end of which is hinged on a transverse axis to the ski, while the upper end is supported by a compression strut whose elasticity is provided by an oil damped spring. The vertical loads are mostly carried by the strut while the side and twisting loads are carried by the frame.

The boss near the top of the frame is cast big enough to accommodate the largest axle in the range of suitability, and there is furthermore enough metal left so that the bore can be made at an angle to the plane of symmetry to be

in accord with the geometry of the undercarriage. The swinging frame thus becomes handed and identified with the type of aircraft for which the ski is intended, but it can easily be removed and exchanged for another frame if the skiis are required for another type (Fig. 15).

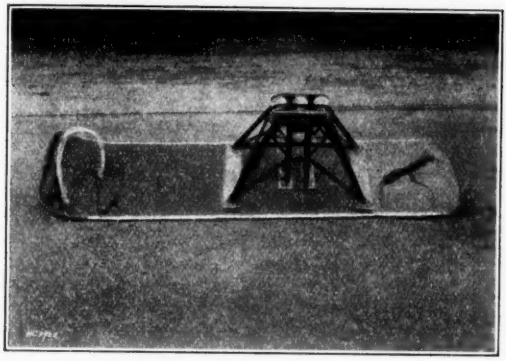


FIG. 14.

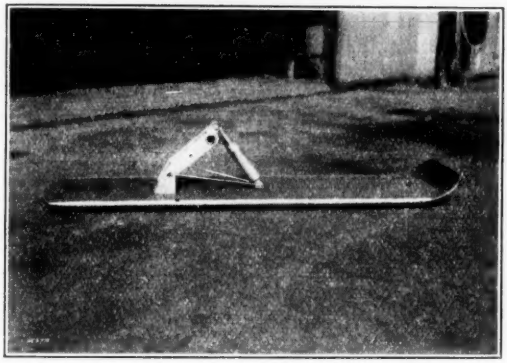


FIG. 15.

Not long ago the R.C.A.F. experimented with a ski which could be mounted directly on to the balloon tyres of an aircraft. A metal casing was mounted on a frame which was articulated to the ski on a fore and aft axis, and was so arranged that it could be opened to receive the wheel and then clamped so as to hold on to the tyre securely. The idea was that the wheel itself provided a shock absorbing and load carrying pedestal, with the advantage that the operator would always have his wheels with him. It was also claimed that the problem of handling in the hangar would be simplified, as the ski could be rapidly removed and the aircraft could then run on its wheels. In the form in which this idea was brought to fruit, it was found that the time of installation and removal compared rather unfavourably with the time of exchange from ordinary skiis to wheels and vice-versa, and there was also a noticeable sacrifice in weight involved, so the experiments were discontinued, but it is quite possible that the idea may be revived at some future date.

Combinations

In certain regions there may be a necessity for a snow landing at one end of a route and a float or wheel landing at the other, or when there is a wide stretch of open water to be crossed, it may be desirable in the interests of safety to use a float seaplane capable of landing on snow or ice. Various attempts have been made to meet these necessities.

Float—Ski Combinations

Ordinary float seaplanes have frequently been landed on and taken off snow or ice, but it can easily be understood that regulation floats are much too vulnerable to withstand much of this kind of service, and the first requisite is to reinforce the bottom. There is nothing very difficult in this, as it is merely a matter of compromising on weight. The only really difficult problem is to provide adequate shock absorption.

Some years ago a manufacturer in the United States in co-operation with Canadian authorities produced a ski float in which the ski portion was external to the watertight vessel of the float, and was mounted through the medium of a nest of springs in a sort of inverted channel underneath the wide flat keel. The total travel of the springs was small, and consequently the shock absorbing was not good at the best of times, and it was reported that even this movement was soon stopped by getting jammed with snow and ice. It may be taken as an axiom that in all winter landing gear working parts should be sealed against the ingress of water or snow.

The only really satisfactory solution for the combined ski-float gear would be one incorporating a float having the best possible water lines and with an internally reinforced bottom, or preferably a double bottom, and a chassis having elastic struts which are the correct length for seaplane work when in a certain position. Means for locking the struts in this position could be provided.

It may not be necessary to have elastic struts all round. The front structure could be of fixed length and provide a pivoting point for the floats, while the rear struts could be made elastic. When the nose of the ski float strikes a hummock, the rear strut would extend, thus allowing the nose to rise slightly and absorb a good proportion of the shock.

A combination gear of this sort was manufactured for the Canadian Government in 1928 for a D.H. 60 Moth, but it came out rather heavy and was not very extensively tested. The idea, however, was shown to be practicable and for a larger aircraft with a bigger margin of disposable load, a suitable design should present no very great difficulties if one remembers that a certain sacrifice in the matter of weight is absolutely inevitable.

Ski-Wheel Combinations

Ski-wheel combinations are not really as simple as ski-float, for in the latter one component performs two functions, whereas in the former, a wheel and a ski are necessary, and furthermore, they must be made so that they can exchange places. An attempt has been made to simplify the matter by having a wheel projecting a few inches through a simple slot in a ski, but this turned out to be neither a good wheel gear nor a good ski gear. It was claimed that the extra resistance caused by the wheel projecting below the ski would hardly be noticeable, but in actual fact, it proved to be very formidable.

In another design, which was intentionally somewhat crude for purposes of economy, the wheel was mounted outboard of the ski on an extension of the axle. A straight axle undercarriage was used. The pedestal consisted of two frames articulated to the ski by athwartship hinges (Fig. 16).

The forward frame carries the axle and a pair of worm-driven pinions which can be operated from the cockpit by means of a universally jointed shaft. The rear frame consists of a pair of toothed racks suitably braced together by

a diaphragm. These racks engage and are held against the pinions in the front frame, so that the latter can be raised and lowered at will. The whole mechanism was enclosed in a canvas bag to exclude water and snow. Tests of this rig proved it to be quite practical and capable of development into a really serviceable design, though the necessity for an axle extension or a special axle is a definite disadvantage.

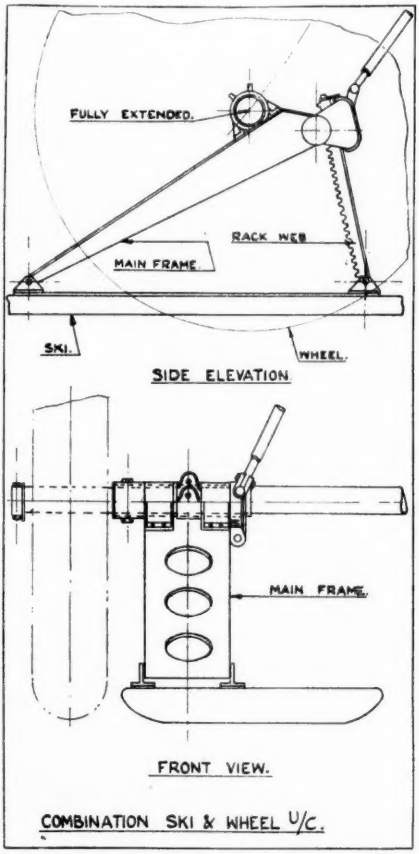


FIG. 16.

Another design of considerable merit, due to Mr. W. H. Perry, of Ottawa, reverts to the idea of a slot through the middle of the ski, but in this instance the ski is connected to the axle by a pair of swinging arms hinged to a casting attached to the ski and rotating about the axle. When wheel landing is required, the ski can be swung forward and upward, the bottom of the ski moving parallel to itself under the restraint of the trimming cables. In the snow landing position the ski is swung downwards and back until the wheel tyre settles into a trough-shaped casting which is supported on the ski shoe on a system of fore and aft hinges which permit the ski to roll. In this design, the wheel acts as the load bearing pedestal. The swinging arms merely serve to operate the

position changing feature and are intentionally slotted at the lower joint so that they cannot take load unless the tyre is unduly deflected.

The swinging arms are extended across the diameter of the wheel and are connected by a cross bar which serves to steady the frame and affords an attachment for operating cables which may be led to a winch in the cockpit. The little projection on the under side of the swinging arm near the middle is merely a positioning stop. The main drawback to this particular design is the elaborate rig necessary for operating the swinging arms. On a narrow bodied aircraft like the D.H. 60 Moth, it is necessary to attach outriggers on each side, one set forward and one set aft of the skiis, to provide anchorages for the pulleys which guide the operating cables (Figs. 17 and 18).

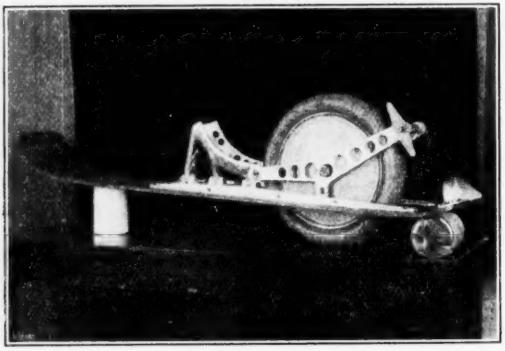


FIG. 17.

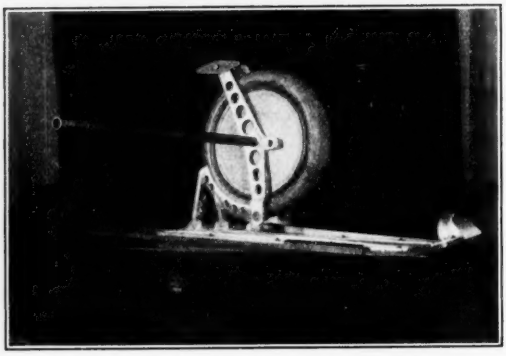


FIG. 18.

A later development of the Perry ski-wheel gear has been developed for a 5,500lb. aircraft, and has been experimented with by the R.C.A.F. This is fundamentally the same as the gear described before, except that the position changing is effected by means of a hydraulic piston connected by tubing to a two-way pump in the cockpit. The gear works very well, and with the refinements that experience will dictate, may be considered as the prototype of an established design (Figs. 19, 20 and 21).

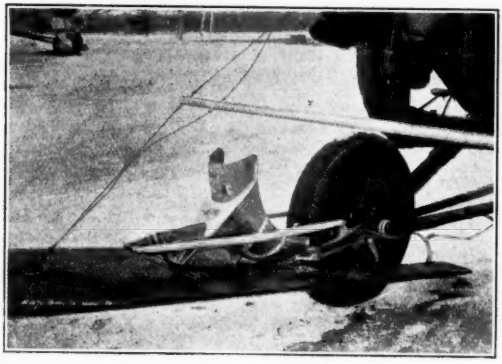


FIG. 19.

FIG. 20.

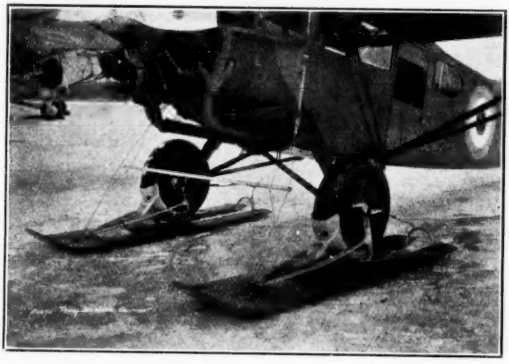


FIG. 21.

Trimming

The maintenance of skiis in their proper attitude in relation to the aircraft in flight is generally referred to as trimming.

It is necessary to allow the skiis to have a considerable freedom of movement in rotation about the axle in order to provide for tail down taxying over reasonably uneven surfaces. The allowance used in the R.C.A.F. is 12° upwards to 33° downwards by the nose. This provides for negotiating an arbitrary standard of roughness of the surface without overstraining the ski or the limiting devices provided. There must be an elastic restraint within this range so that when the aircraft is in the air, the skiis will be held in the position for minimum drag.

The simplest, cheapest and most popular restraining medium is rubber shock absorber cord. This is used in series with a steel cable and in parallel with a short length of steel safety cable which takes over the load when the skiis reach their limit of rotation. It is, of course, necessary to have a cable at the front and at the rear of the ski. Opinion among commercial operators in Canada favours a plain cable at the rear, shock absorber cord being introduced at the front only. The R.C.A.F. prefer to introduce the elastic cord both at the back and the front, so as to make the possibility of failure of the rear cable extremely remote, as this failure might allow the ski to rotate upwards and foul the airscrew. The time when the rear cable is likely to be overstrained is when an aircraft begins to taxi over, or is hauled over, a pile of frozen snow. The front of the ski may then be raised to the limit allowed and a heavy load comes suddenly on the rear trimming cable.

Trimming cables should always be rigged so that in the flying position they are pulling as nearly as possible at right angles to the ski. Some time ago a trimming cable was mounted on an R.C.A.F. aircraft so that it leaned backwards considerably. As the ski began to rotate downwards during a dive, the cable approached nearer and nearer to the axis of rotation until the restoring moment became less than the negative pitching moment, due to the air forces, and the ski went right out of control. A serious accident was only narrowly averted.

The rigging of trimming cables is a matter of some judgment and experience. It is usually done with the aircraft slung in the air, so that all load is off the undercarriage and sufficient initial tension is applied in winding the shock absorber cord to make the ski quite stiff, without unduly shortening the available travel of the undercarriage. Checking is then done with the weight supported on the undercarriage to make sure that the required freedom of movement is available for taxying. The length of the rear check cable is often fixed by the necessity of preventing interference with the airscrew, while the length of the front cable is usually that which will allow the full 33° downward motion when the undercarriage is loaded with its ordinary static load.

It has been found that rubber shock absorber cord goes lifeless if left under tension in the extreme cold, and consequently trimming cable shackle plates are provided with an extra hole which can be used for rigging a light block and tackle, which will permit one man to unharness the cables and leave them slack.

Trimming cables are untidy looking and probably cause a considerable amount of air resistance. Their place can be taken by a telescopic trimming leg which extends or contracts against the action of springs. Such a leg with springs working in compression is illustrated in Fig. 9. This leg is neater in appearance, and is probably cleaner aerodynamically, but it is more expensive, less universal in applicability, and is not so easy to repair in the field as a system of cables; and furthermore, nearly all the spares for trimming cables are carried in the form of stock materials having a variety of applications. These last considerations explain why the R.C.A.F. still use the cables, though it is moderately certain that modern high speed aircraft will require the leg.

Several varieties of trimming devices relying on spring restraint acting from the end of a lever attached rigidly to the axle, but virtually forming part of the pedestal assembly, have been used. It is only necessary to illustrate one as the same general idea is involved in all (Fig. 13).

The main disadvantage of this type of trimming is that it imposes heavy torsional loads on the axle, and aircraft with straight through axles are not usually suited for this, as the axle is left free to rotate in relation to at least one side of the undercarriage.

The National Research Council of Canada have done some interesting wind tunnel tests to determine the pitching moments of one small commercial type ski and two of the larger R.C.A.F. standard skiis (Fig. 22).

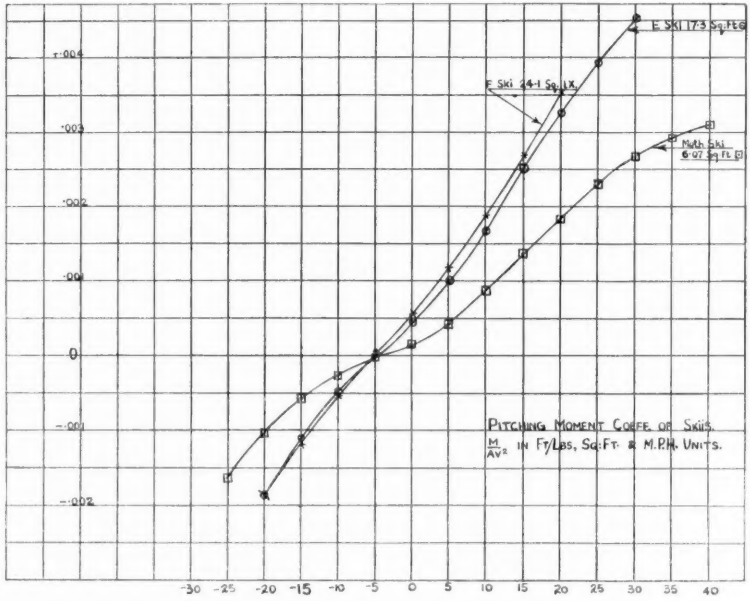


FIG. 22.

The results of these tests serve to demonstrate that the problem of trimming skiis on aircraft that have a speed of 150 m.p.h. or more becomes more complicated, especially on military aircraft which require to do rapid manœuvres involving appreciable inertia forces. A simple restraining system involving a spring leg or a pair of cables would have to be made so stiff to counteract the highest possible aerodynamic and inertia forces that the taxying and landing qualities might be seriously impaired. The following solutions have been advanced :—

(*a*) To install a restraining system suitable for taxying and landing conditions and provide means for locking and unlocking in the air. These means could be—

(i) Hand manipulated.
(ii) Automatic as a function of the dynamic pressure.

This solution has not been pursued because it relies either on another " gadget " or on the already hard pressed human element.

(*b*) To stabilise the ski in pitching by aerodynamic means. This solution is now being pursued by experiments in the wind tunnel of the National Research Council of Canada. Acting on a hint, for which Canada is indebted to Sweden, a standard R.C.A.F. size " E " ski has been fitted at the rear end with a series of flat plates, having a width equal to that of the ski and making an angle of 135° with the flat portion of the ski bottom. The chords of these plates measured from the line of intersection with the top surface were 9in., 12in. and 15in. The effect of these flaps is shown in the curves of Fig. 23.

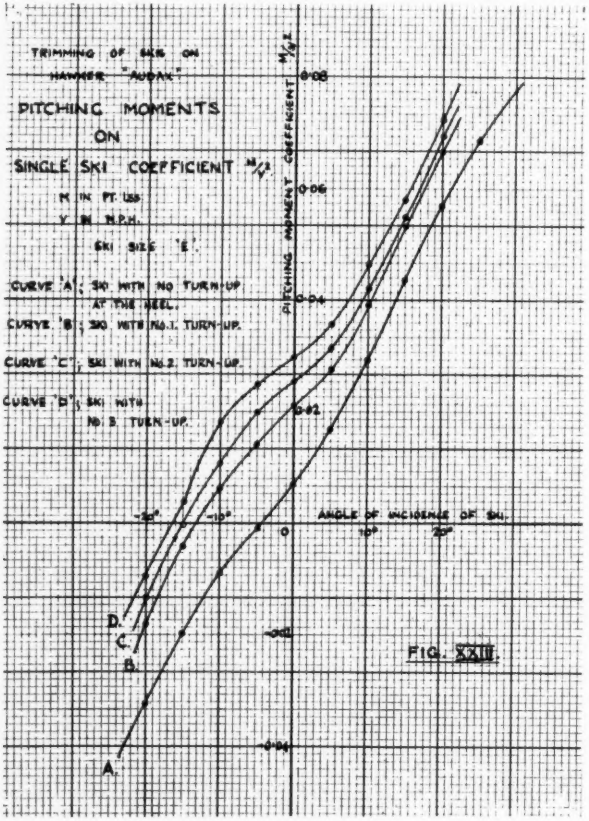


FIG. XXIII.

It will be observed that there is some modification to the slope of the pitching moment curves in the region of incidence zero to minus 15°, and that the curves have been moved bodily over to the left so that the incidence at which transition from positive to negative moment takes place is well over on the negative side and beyond the range of incidence that is likely to be encountered in flight. Admittedly, the positive pitching moments attain a considerable figure, but a limit stop against upward movement of the ski nose is not difficult to provide, and furthermore, as the upward limit is set at about twelve degrees or less, the ski in this limiting altitude will not affect the control of the aeroplane to any

dangerous extent. The addition of a turn up at the rear end of the ski will, therefore, go a long way towards solving the trimming problem in high speed aircraft. If the turn up is made curved instead of being just a flat plate, it will be slightly more effective, and the air flow will probably be much smoother.

It would be possible to obtain complete aerodynamic stability by fixing a stabiliser plane above and behind the ski on an outrigger, and this possibility is now being investigated by the National Research Council of Canada.

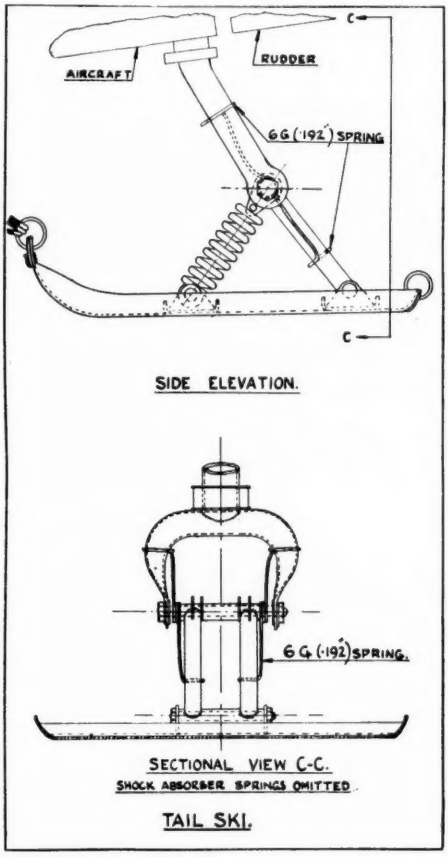


FIG. 24.

Tail Skiis

The earliest types of tail skiis consisted of a large spade or spoon-shaped surface made of wood or metal and fixed on as a substitute for the ordinary land type tail skid shoe. It was found that these were not entirely satisfactory as the extension lengthwise caused increased moments which resulted in damage to some part or other of the aircraft at the rear end. Manufacturers in Canada make tail skiis which are similar in every way to the main skiis and which are provided with a miniature pedestal supported on an axle or hinge pin on the tail skid or tail wheel fork. The majority of aircraft on the North American

continent are now fitted with tail wheels, so that the mounting of a pedestal is a simple problem. The Canadian Department of National Defence, though using a number of the plain wooden tail skiis, favours a wide pan-shaped ski of light alloy about $\frac{1}{8}$in. thick and curved up about two inches around all the edges and suitably stiffened with angles or channels inside the pan. The underside is provided with a pair of half-round iron runners which prevent wear of the pan on hard surfaces, and which can be easily and cheaply replaced when worn down. These runners are fitted solely for wear, and have no directional functions.

Trimming of tail skiis is often effected in a similar manner to that of the main skiis, though the problem is sometimes complicated when the skid is of the steerable or swivelling type. On skiis which are supported from a tail wheel fork, a very simple method of trimming has recently been tried out with success. A simple torsion spring is wrapped round the supporting axle and one end is anchored on the limb of the fork, while the other is anchored to the pedestal. A front check cable of steel is added to preclude all possibility of the ski digging right down into the snow on encountering a drift. It is advisable to rivet a doubling plate or patch to reinforce the point of anchorage of this cable on the light alloy pan.

On some aircraft the tyre of the tail wheel is relied upon to provide all, or nearly all, the shock absorption. It is then necessary to provide a substitute for this in the structure of the tail ski pedestal. A simple solution is illustrated in Fig. 24.

Handling on the Ground

When ski equipped aircraft have to be taken into or out of hangars, a considerable problem is encountered which must be dealt with by the provision of special equipment. In order that the natures of the difficulties may be more clearly understood, a short description of the conditions surrounding a hangar will not be out of place. In the spring months when there is a considerable depth of snow on the aerodrome and the sun is beginning to get fairly high and warm, the heat reflected from the hangar walls and doors melts the snow round the building. Where the snow has been partially removed by human agency, such as in front of the doors, the surface quickly becomes bare, and this bare spot quickly extends towards the aerodrome, sometimes going beyond the bounds of the prepared apron and reaching a considerable area of the natural ground which becomes soft and sometimes muddy. It is this soft ground which is the cause of the greatest difficulties, as it precludes the use of small-wheeled jacking trollies of a size suitable for wheeling under the aircraft.

With small aircraft it is quite usual to remove the skiis and put on the wheels, or to rig the wheels on to a special stub axle supported in an axle housing contrived in the pedestal some inches below the regular axle housing. These operations can be done without a jack, as a small machine can easily be lifted by raising one wing at a time.

On larger aircraft it is necessary to use a machine to give enough mechanical advantage to enable one man, or possibly two men, to lift the aircraft. A simple arrangement which can be used on aircraft with the " Oildraulic Pedestal " consists of a long and strong axle which is passed under the supporting points of the aircraft axle and is provided with wooden saddles to conform to the shape of the pedestal. A pair of ordinary garage jacks are then placed under this axle as near to the undercarriage struts as possible, and the aircraft is then lifted high enough to permit its own wheels to be fitted on to the ground handling axle. The jacks are removed and the aircraft can be wheeled away. The jacks are of the hydraulic type and run on a set of small caster wheels. A metal frame connects the pair of jacks and the pumping handles are connected together by a bar so that one man operates both simultaneously. On soft ground it is necessary to lay planks under the jacks.

Another device which has recently been tried with success on an aircraft of 5,500lbs. gross weight consists of a specially designed crank. The journal is supported in the hollow end of the aircraft axle, and the wheel, which properly belongs to the aircraft, is fitted on the "crank pin." A fairly long lever is attachable to the crank web. The rotation of the crank by means of the lever lowers the wheel until it takes the load, and when it is in the correct position, a strong pin is passed right through special holes in the axle and in the journal to lock the crank. This process is fairly rapid, and two men can deal with an aircraft in a few minutes, but it has the disadvantage that heavy torsional loads are imposed on the aircraft axle. Standardisation of this device would entail standardisation of the internal bore of aircraft axles and of the drilling of holes for the attachment of axle caps, which holes can be used as the locking holes for the crank journal (Fig. 25).

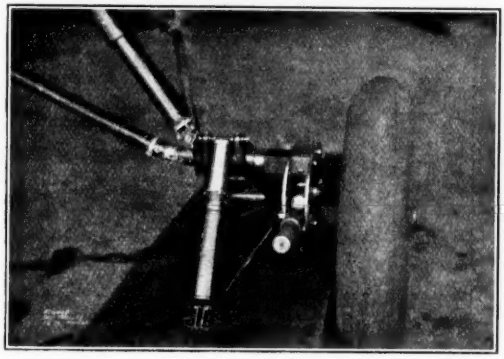


FIG. 25.

Another device has recently been produced for a small aircraft and is based on the same fundamental principle, but the crank is rotated beyond dead centre and comes against a stop. This is stable at least in one direction and can therefore be operated by one man.

A low frame on which the aircraft can be placed and running on a large number of long small diameter rollers has been tried, but the idea was abandoned because the frame was very heavy and difficult to manœuvre and was not capable of running on soft ground or snow.

A pair of skids or false skiis consisting of rough planks fastened together, on to which the main aircraft skiis can be skidded, affords a solution having some merit, though it necessitates a tractor or a lot of man power to operate.

The skids are easily made from common materials, and interchangeability is no problem, but they are difficult to manœuvre and consequently they are only really suitable for use when aircraft do not have to be packed in closely.

Aircraft cannot be left standing on the bare snow for any length of time for fear that the ski bottoms will freeze down, and it is quite a usual thing to provide short lengths of wood on to which the skiis are dragged. The skids mentioned above would serve just as well, if not better, and would be particularly useful for military aircraft which may be lined up in readiness for some urgent call.

A scheme which has been proposed, but which has not yet been tried, consists of a combination of the long axle and the crank device previously described; in fact it is an adaptation of the vehicle known as the "timber devil." A long cranked axle with a large wheel at each end could be wheeled into place

TABLE I.

Snow.	Overlying.	Hard Ground.	Soft Ground.	Boggy Ground.	Ice.	Soft Snow Undisturbed.	Snow Hard Packed.	Snow Crusty.	Slush.
Dry, Soft and Fluffy	Deeply	Good	Good	Good	Good	Fair	Good	Good	Fair
	Not over 6in.	Fair	Fair	Bad	Fair	Good	Excellent	Excellent	Bad
Dry, Soft and Powdery	Deeply	Good	Good	Good	Good	Fair	Good	Good	Fair
	Not over 6in.	Fair	Fair	Bad	Fair	Good	Good	Good	Bad
Dry, Hard and Granular	Deeply	No experience of this in deep deposits.							
	Not over 6in.	Poor	Poor	Poor	Fair	Poor	Poor	Fair	Poor
Wet, Soft and Fluffy	Deeply	Poor	Poor	Bad	Bad	Bad	Poor	Poor	Poor
	Not over 6in.	Bad	Bad	V. Bad	Fair	Fair	Fair	Fair	Bad
Slush	Deeply	Poor	Bad	Bad	Bad	Bad	Bad	Bad	Imposs.
	Not over 6in.	Poor	Bad	Bad	Poor	Bad	Poor	Poor	Imposs.

TABLE II.

TYPICAL SKIIS FOR AIRCRAFT FROM 1930 TO 8,000LBS. GROSS WEIGHT.

SCHEDULE OF WEIGHTS AND SIZES.

Component.	Pedestal Fitted.	Size Overall.	Bearing Area (set).	Weight per set lbs.	Weight as per cent. of gross weight. Loaded 140 lbs. per sq. ft.	Loaded 200 lbs. per sq. ft.	Remarks.
Ski, Curtiss-Reid R.1160-2	C.R.1074	5′ 2¾″ × 1′ 2″	9.2 sq. ft.	66	5.1%	3.6%	
Ski, Curtiss-Reid R.1119-11	C.R.1074	6′ 9″ × 1′ 6″	15.0 ,,	130	6.2%	4.34	Self-trimming pedestals.
Ski, Curtiss-Reid R.1127	C.R.1129	9′ 3″ × 2′ 1″	31.5 ,,	266	6.0	4.23	
Ski, RCAF, Size C	Oildraulic J	6′ 8″ × 1′ 7½″	14.5 ,,	170	8.4	5.85	
D	,, J	7′ 5″ × 1′ 9″	18.5 ,,	186	7.15	5.03	Shock absorbing pedestals.
E	,, S	8′ 8″ × 2′ 0″	28.0 ,,	286	7.27	5.1	
F	,, S	10′ 3″ × 2′ 4″	40.0 ,,	384	6.83	4.8	
Fairchild L.1015C	Fairchild	9′ 11″ × 2′ 0″	31.0 ,,	250	5.75	4.04	Plain pedestal.
Perry Ski-Wheel Combination	Perry	9′ 6″ × 2′ 4″	30.8 ,,				
Without Wheels				325	7.53	5.28	
With Wheels				437	10.1	7.10	Wheels 112lbs.
Tail Ski.					As per cent. of aircraft gross weight.		
RCAF 4724 Bellanca	—	20″ × 18.5″	2.57 ,,	10	.23		Spring pedestal.
,, 4728 Wapiti	—	32″ × 14.5″	3.2 ,,	12.3	.224		Virtually no pedestal.
Curtiss-Reid R.1149-40	—	16″ × 8½″	0.95 ,,	2.6	.15		Ditto
X.248	—	22″ × 12½″	1.3 ,,	6.75	.20		Small pedestal.
Fairchild, wooden		39″ × 14½″	3.93 ,,	18.0	.30		Ditto
Oildraulic Pedestal J	—	—	—	58	1.45		Gross Wt. 4000lbs.
,, ,, S				96	1.6		,, ,, 6000lbs.
,, ,, S in magnesium				80	1.33		,, ,, 6000lbs.

Light alloy pan.

NOTE.—Skiis for larger aircraft have not been made in Canada in sufficient quantities to afford reliable statistics.

just in front of the ski pedestals and spanning the skiis, with the crank in the lowered position. A chain over the crank could be hooked to special fittings on the ski, and then the crank could be raised by means of a lever which would then be secured to the ski itself by some specially provided anchorage device. This scheme has an advantage over the schemes which involve lifting at the aircraft axle, in that, on shock absorbing pedestals, no provision need be made for the extension of the shock absorber unit when relieved of load. Another variation of this would involve a straight axle carrying a pair of ratchet operated winches for raising the load. This variation would require less clearance space, as no long lever is necessary. As the point of support is necessarily in front of the aircraft axle, it would be necessary to provide some means for keeping up the heels of the skiis. One way to do this would be to rig a ring into the rear check cable, so that this cable could be reefed to a shorter length, in which case it would carry a load which would bear a definite relation to the weight of the aircraft.

The problem of handling the tail of heavy aircraft has already received a great deal of attention in England and other countries, and snow conditions will only add a few complications to this.

THE CASE FOR VERTICAL FLIGHT

BY

HAVILAND H. PLATT, M.E., M.I.AE.SC.

If the man in the street is asked his opinion of the future of aviation, he will almost invariably reply, " Everyone will have an aeroplane on his roof and go straight up like this." Whereupon he will go through the traditional motion of the spiral staircase joke.

The expert pilot or technician of to-day, overhearing this remark, smiles in a superior way. In his mind are two contrasting pictures: That of a city over which whirligigs are springing up from adjacent roof tops; and that of the vast empty spaces of even the busiest airport as he knows it. He thinks of the scores of pathetically abortive monstrosities called helicopters that have been built and tested in the years since human flight first became a reality. One picture seems as far from the other as the moon is from the earth and flying to the moon seems as practical as rising vertically from a roof.

The full lengths of the apparent folly of the lay prophet will not be defended here. General private use of aircraft, whether vertically or horizontally operating, involves other uncertainties than those of mechanics, such as wind gusts, distance judgment and blue funk paralysis.

The aim rather will be to indicate what utilities may conservatively be foreseen for vertical flight, in what ways it would have the advantage over present types of flight and how great these advantages would be—that is, if vertical flight could be practically realised.

A presentation of the aerodynamics of vertical flight will be given to show that the practical solutions of its main problems are not so remote as a consideration of the record of failures would lead one to believe.

Finally, a specific solution of these problems will be briefly set forth.

It seems conservative enough to assume that a reasonably stable and controllable vertical lift machine could be safely flown by a suitably licensed pilot from a clear space one hundred feet on a side. In the field of private flying this should mean that the slightly adventurous country estate owner may, by devoting a half acre of his ground to the purpose, maintain a machine in which he may go picnicking or visiting anywhere. In the city the same purpose could be served, with only slightly less convenience, by large aircraft garages with flat roofs, probably surrounded by guard fences and possibly by wind breaks, and equipped with lifts to convey alighting and departing aircraft to and from the storage floors below. In these garages the city dwellers might keep their machines and they would afford visitors from the country landing and storage facilities.

Fleets of taxis would be based on such garages and would be available for hire at any time.

The business man, whose time is valuable, would find private ownership and the taxi service economic assets in saving a large proportion of his travelling time.

Aside from these specific utilities, however, it would be rash at present to predict for private ownership a greater future than that of a sporting and luxurious convenience.

In the field of commercial transport, however, the outlook is very much more clearcut.

Small in total prospect, but first in present availability, comes airport feeder service. Vertical flight would enable air travellers to take off from the centre of the city for transfer to air liners at the outlying airports, with savings of time of one-half hour or more at each end of the journey. There is an impression in many technical quarters that the advantage of strictly vertical performance, in this service, over an angular climb, which can get out of a space six hundred feet square, is not worth the difficulties and complications that may be involved. A concrete example will serve to show how great is the practical, economic disparity between the two types of performance.

The carrying charges of a suitable central city property, including rental, interest and maintenance, will probably not be less than two shillings per year per square foot of field or platform area. The costs per annum are then for the vertical flight machine, £1,000; and for the inclined flight machine, £36,000. If subsidised by the free use of a public owned property, the latter might be operated successfully. But when called upon to pay its own way, as it eventually must be, its prospect is plainly hopeless.

As a natural outgrowth of airport feeder service, we may anticipate general suburban bus service, point to point city bus service and inter-urban bus lines with local stops. The suburban business commuter may thus be saved three hundred hours of his time every year and the influence of the city may be extended a hundred miles or so into the country in all directions, with consequent enormous land value increments.

It should be noted well that these services, of great economic importance, are in no way competitive with the accomplishments of existing aircraft and therefore the question of speed, in which the vertical flight design has generally been thought of necessity inferior, is immaterial, provided only the speed is substantially higher than that of ground vehicles.

Again, without assuming high forward speeds, considerable military and naval utility can be foreseen. Avoiding the debatable ground of the transport and observation usefulness with an army, the high climbing rates which seem assured, coupled with the dodging ability inherent in sudden stops and vertical climbs and drops, give a new manœuvrability of distinct tactical value. The ability to alight on, as well as to rise from, a platform on a gun turret, probably without regard to the course or speed of the vessel, should give a great new value to aircraft for naval observation work.

We come now to the consideration of the possibility of practical realisation of an aircraft capable of vertical flight. Strangely enough the fundamental problem, which is so often considered insuperable, is in reality by far the most easily disposed of. This is that of obtaining sufficient sustaining force to lift the necessary weight without forward motion.

The basis for calculating the power required to lift a given weight is the air momentum theory, which forms also the basis of standard propeller practice. The appropriate formula is

$$P = W\sqrt{\{(1/2\rho)(W/A)\}}$$

in which P is the power, aside from mechanical and air friction losses, required to provide a static thrust equal to the weight of the machine, W. This will be referred to as the induced power. ρ is the air density and (W/A) is the air column loading in lbs. per square foot of cross-section of the downwardly displaced column of air. In conformity with helical propeller practice this may be referred to as the disc loading.

The significance of this formula is clearly shown by varying the disc loading and plotting a curve of horse-power required to support a given weight against disc loading. Such a curve is given at b in Fig. 1, the assumed weight being 3,000lbs.

In addition to the induced power, there is also of necessity loss of power in overcoming the profile drag of the rotating wings. This, being in the nature of

air friction, does not contribute to the support. The exact amount of this loss is, of course, dependent on the specific type and design of any machine, while the induced power requirement is entirely independent of such considerations. Curve *c* gives the calculated profile drag power losses for a typical example. Curve *a* is obtained by adding the values of curve *c* to those of curve *b* and gives the combined power requirement for hovering. The profile losses being only a fraction of the induced power, and the change in profile losses not being very great from one design to another, this curve may be taken as a fair approximation to what may be expected of a practical design.

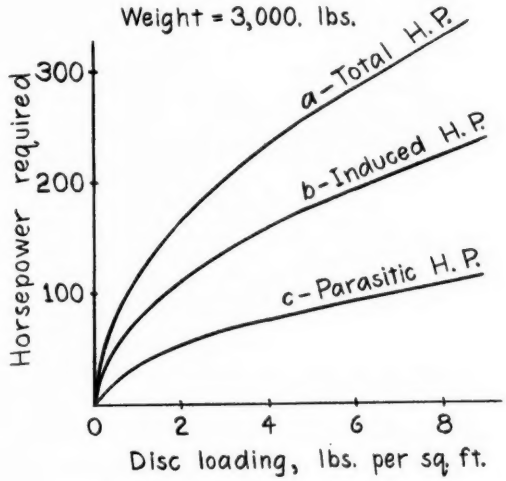


FIGURE 1

Two other phases of performance are equally dependent on the disc loading. These are the vertical climbing velocity and the vertical descent velocity in autorotation. Since all the power required for supporting the weight and overcoming friction have been taken care of in calculating the hovering power requirement, it is evident that all the remaining power available may be put directly into the work of overcoming gravitation. Whence

$$P_c = W V_c$$
$$\text{and } V_c = P_c / W$$

P_c being the difference between the engine power available and the power required for hovering, and V_c the vertical climbing velocity.

The autorotative vertical descent velocity, it has been found, may be expressed in terms of the familiar parachute formula

$$W = K \rho A V_d^2,$$
$$\text{whence } V_d = \sqrt{\{(1/K\rho)(W/A)\}},$$

V_d being the velocity of free vertical descent, and K a constant which, for efficient blade settings, may be given the value .6.

Fig. 2 gives curves showing the effect of varying disc loading on these two velocities, the available power being assumed to be 285 h.p. for 3,000lbs.

It should be noted that these performances apply only to the condition of zero horizontal air speed. The performance in each case is much improved by

even small horizontal velocities, the extent of this change being dependent on specific features of the design.

Since it is estimated that a machine, including the pilot, a normal pay load and a 300 horse-power engine, can be constructed with a weight of 3,000 pounds, it at once becomes apparent that the only requirement for the best vertical performance is that its lift elements shall be spread out over as great an area as possible. Also it is seen that, from a lift point of view, any design has practical possibilities if it can keep the disc loading below six or seven pounds per square foot.

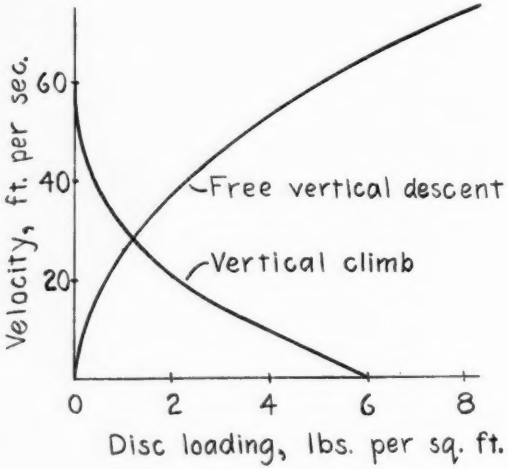


FIGURE 2

When we consider that the disc loadings of present autogiros are less than two pounds per square foot, the ease of meeting the vertical performance requirements, if considered alone, becomes apparent.

From this point on, however, the pathway of the vertical flight designer is beset with pitfalls, each of which must be mapped out in advance and carefully avoided if any success at all is to be achieved.

The most important of the minor problems which must be mastered are those of:—

Stability.
Controllability.
Adequate forward speed.
Safe emergency landing.
Gyroscopic effects.
Torque reaction.

Of these, the last one, that of the torque reaction, is by far the most obstinate. If one attempts, as has so often been done, to neutralise the torque by rotating two or more lift screws in opposite directions, troubles of weight and mechanical complexity, in addition to those enumerated above, pile up to a hopeless extent. The consequences are the monstrous designs which have given the helicopter such a very bad reputation.

It was the search for another solution of the torque problem—one which might keep clear of the tangle of secondary troubles—which led to the conception of the cyclogiro. As is so often helpful, an appeal to nature provided the basis

of the idea. How do the hovering birds and insects dispose of the torque reaction? The answer was soon found by observing that the wings of a bee, for example, as it hovers before a flower, are propelled with a rotary motion about a horizontal axis, thereby enabling the torque reaction to be counterbalanced by the weight of the body suspended below the rotation axis.

While the blurred outline of the wing trajectory gives no clue to the actual angles of the wings at points about the circle, and the specific design is obviously unsuited to engineering materials, nevertheless it is apparent that all that is needed is to devise a system of aerofoils rotating about a transverse axis which can be given lift angles somewhere in the rotation path when vertical flight is wanted, and a combination of lift and horizontal thrust angles when forward motion is required. If the precaution of seeing that nowhere in any performance phase do relative angles close to the stall occur, thus avoiding excessive profile drag losses, the sequence and arrangement of angles is unimportant. This being so, full attention can be given to the sole factor of mechanical simplicity.

The design of the cyclogiro, a sketch of which is shown in Fig. 3, is the result of this search. The basic mechanism shown diagrammatically in Fig. 4 is found to provide very simply the necessary solution of the blade angle changes.

The Cyclogiro

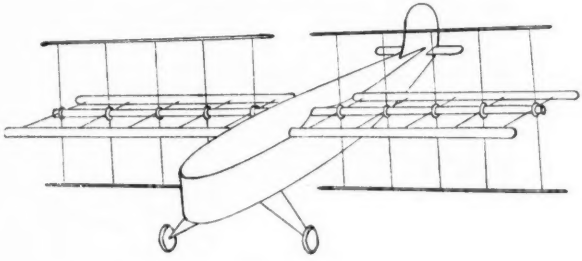


FIGURE 3

The individual blades are pivotally attached, at their combined centres of gravity and pressure, to supports radially disposed about the central hollow shaft. Since the centrifugal force is, in operation, much greater than any possible aerodynamic force, these supports need be little more than streamline wires, and have therefore not much weight or air resistance. An eccentric is mounted so as to be rotatable about the shaft axis at the inner end, its angular position being under the pilot's control. Attached to a strap on the eccentric are radial wires extending to pivots near the trailing edges of the blades. The trailing edges are thus constrained to rotate about the eccentric centre while the supporting pivots rotate about the shaft centre. With the eccentric centre placed below the shaft, as in the position *a* of Fig. 4, each blade passes successively through the four positions shown, during each revolution. A lift angle is provided at the upper and at the lower position, the requirement for a vertical force being thus met. When turned to the position *b*, the blades in the horizontal position give horizontal thrust forces, while that in the lower position still has a lift angle. Since its relative velocity is increased by the motion of the whole machine in the direction indicated, this lesser angle is still sufficient to support the machine, even though the upper blade position furnishes very little force.

A one-piece eccentric would be incapable of permitting changes of blade angles. Consequently a compound eccentric is used, made up of two separate units, one mounted on the other. When the two component eccentricities are in

line, the resultant eccentricity has its maximum value, while when they are turned to oppose each other the net eccentricity is zero.

These four component eccentricities, two for each rotor, are connected by drum and cable to a control stick and a pedal bar of standard type in such a way that the proper combination of pedal and lateral stick motion change the

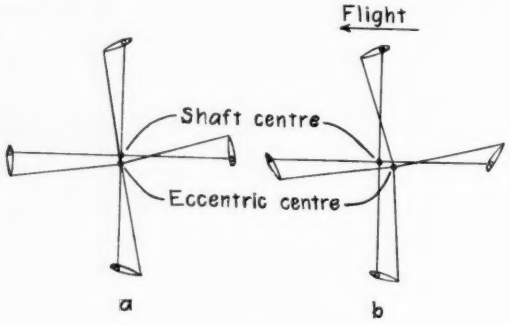


FIGURE 4

lift and thrust differentially on the two rotors, thus causing any desired yaw or roll. Straight fore and aft motion of the stick takes care of longitudinal control.

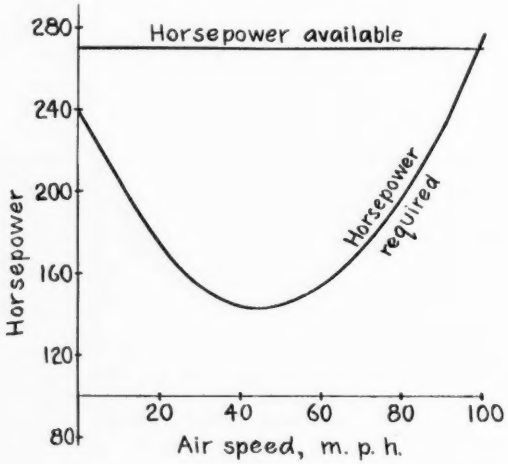


FIGURE 5

A second lever is provided at the side of the control stick to control changes of blade angle by rotating both outer eccentrics relative to the inner pair. By proper proportioning of the control parts, all routine changes of blade angle can be made to occur automatically with motion of the control stick only. The additional lever is therefore used, only in case of power failure, to adjust the blade angles for autorotation, an overrunning clutch permitting rotation free of

the engine. The angle control lever may be used again to increase the blade angles as the ground is approached, the inertia energy of the rotors being thus applied to increase the lift force momentarily.

Lateral and longitudinal stability in vertical flight turn out to be inherent in the machine, the blade supporting arms acting as fins disposed fore and aft, while the blades themselves constitute similar fin area in transverse vertical planes as they move up and down. Since both sets of fins are at all times moving rapidly and are placed well above the centre of gravity, they provide very effective stability against pitching and rolling oscillations, particularly in vertical operation. Conventional fixed tail fins supplement them in forward flight.

By proper selection of the direction of rotation, gyroscopic precession resulting from a turn becomes of advantage in assisting the correct bank. Internal gyroscopic forces within the rotors may be taken care of by slack diagonal bracing, which allows a certain amount of cushioned end play to the blades.

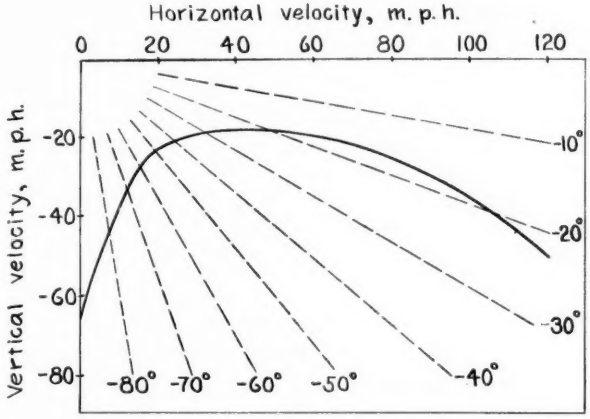


FIGURE 6

It is thus seen that, in so far as qualitative considerations are concerned, every one of the detailed requirements of a practical machine can be met.

An aerodynamic analysis by Mr. Wheatley,* of the National Advisory Committee for Aeronautics, leads to the level flight performance curve of Fig. 5 for a conservatively assumed set of parameters, the disc loading being 5.2lbs. per square foot.

The corresponding autorotative performance from the same source is shown in Fig. 6. His computations also give the following rate of climb values for a 300 h.p. 3,000lb. machine:—

Vertically, 650 ft. per min.
At an angle of 30 degrees, 1,500 ft. per min.

A later paper by the same author† estimates that, when thoroughly cleaned up, forward speeds equal to those of corresponding conventional aeroplanes are to be expected.

* "Simplified Aerodynamic Analysis of the Cyclogiro Rotating-Wing System," by John B. Wheatley, Technical Note No. 467 of the N.A.C.A.

† "Rotating-Wing Aircraft Compared to Conventional Airplanes," by John B. Wheatley, Journal of the Society of Automotive Engineers, April, 1934.

The National Advisory Committee for Aeronautics, in addition to the theoretical study reported by Mr. Wheatley, have placed the cyclogiro on their experimental research programme and have in preparation a series of tests, on a model large enough to be free of serious scale effects, which are soon to be conducted in their laboratory at Langley Field.

To conclude, it has been shown that a large and economically very important field of utility awaits the development of an aircraft capable of vertical flight; that the aerodynamics of vertical flight admit of very attractive performance possibilities; that, in spite of the many failures to date and the considerable difficulties of detail involved in a practical solution, there is no reason to despair of its accomplishment.

In view of this situation, it seems that vertical flight is worthy of a great deal more attention, both in serious technical study and in concerted research, than it has hitherto been accorded.

THE STRENGTH OF AEROPLANE WING SPARS WITH END LOADS VARYING IN ANY ONE BAY

BY

CAPTAIN J. MORRIS, B.A., A.F.R.AE.S.

In the stressing of aeroplane wing spars account must be taken of end load, particularly when this end load is compressive. When the end load is continuous over each bay the strength of the spars may be calculated by what is known as the Berry method. It may happen, however, that owing to drag loads the end load may vary in the different portions of a bay, and in such circumstances it is customary to average out the various end loads and to regard this average load as acting over the whole bay. This practice is based on an investigation by Miss Cave-Browne-Cave in which the stability of a strut was considered, having regard to different compressive loads acting over each of the two portions into which the strut was divided. Miss Cave, who dealt only with compressive loads whose lines of action were parallel, found that the failing load for the whole strut was very approximately equal to the arithmetic mean of the two compressive loads which in combination produced instability failure.

It is required to extend the investigation of this problem to embrace tensile loads and if possible to take account of conditions which approximate more closely to those of an actual aeroplane wing spar.

In general, extreme conditions may be expected in the particular case of a single bay monoplane wing bracing, so we will deal with this case first.

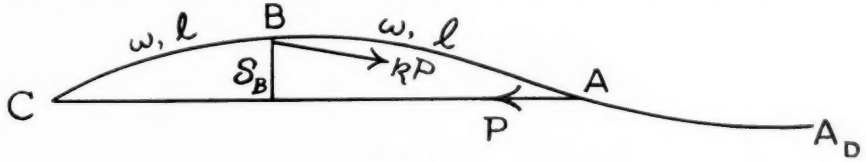


FIG. 1.

Referring to Fig. 1, let A_0ABC be a wing spar pin-jointed to fixed supports at A and C and having the portion AA_0 overhung. Let a compressive end load P act at A along AC and let a load kP act at B along the line BA. Let $CB=BA=AA_0=l$ and let there be a uniformly distributed load w over the whole spar which is supposed to be of uniform section.

Let M_A, M_B, M_C be the bending moments at A, B and C and let δ_B be the deflection of B above CA.

Let $\alpha=\sqrt{(P/EI)}\,(l/2)$ for the portion AB and $\alpha_k=\sqrt{\{(1-k)P/EI\}}\,(l/2)$ for the portion BC.

Then $\alpha_k=\alpha\sqrt{(1-k)}$ or, if $k>1$, $\alpha_k=\alpha\sqrt{(k-1)}$.

Applying Berry's generalised theorem of three moments and having regard to the deflection at B, we have

$$M_A f(\alpha)+M_C f\{\alpha\sqrt{(1-k)}\}+2M_B[\phi(\alpha)+\phi\{\alpha\sqrt{(1-k)}\}]+(12EI/l^2)\delta_B=(wl^2/4)[\psi(\alpha)+\psi\{\alpha\sqrt{(1-k)}\}]^* \quad . \quad . \quad (1)$$

* If the three consecutive supports are deflected (positively upwards) then Berry's generalised equation of three moments is

$$(l_1/I_1)\,M_A f(\alpha_1)+(l_2/I_2)\,M_C f(\alpha_2)+2M_B[(l_1/I_1)\phi(\alpha_1)+(l_2/I_2)\phi(\alpha_2)]+(6E/l_1)(\delta_B-\delta_A)+(6E/l_2)(\delta_B-\delta_C)=(w_1l_1^3/4I_1)\psi(\alpha_1)+(w_2l_2^3/4I_2)\psi(\alpha_2)$$

$$\text{or } M_A f(\alpha)+M_C F\{\alpha\sqrt{(k-1)}\}+2M_B[\phi(\alpha)+\Phi\{\alpha\sqrt{(k-1)}\}] + (12EI/l^2)\delta_B=(wl^2/4)[\psi(\alpha)+\Psi\{\alpha\sqrt{(k-1)}\}] \quad . \quad . \quad (2)$$

according as k is $<$ or >1, and where f, ϕ, ψ, F, Φ, Ψ, are the usual Berry functions.

Taking moments about B and C in succession we find

$$M_B=M_A-S_A l-P\delta_B+\tfrac{1}{2}wl^2$$
$$M_C=M_A-2S_A l-2kP\delta_B+2wl^2$$

where S_A is the shear immediately to the left of A.

Eliminating S_A from these moment equations we obtain

$$2(1-k)P\delta_B=M_A-2M_B+M_C-wl^2 \quad . \quad . \quad . \quad (3)$$

By substituting this value of δ_B in (1) or (2) we obtain

$$M_A[f(\alpha)+3/2(1-k)\alpha^2]+2M_B\left[\phi(\alpha)+\left\{\begin{matrix}\phi\{\alpha\sqrt{(1-k)}\}\\ \Phi\{\alpha\sqrt{(k-1)}\}\end{matrix}\right\}-3/2(1-k)\alpha^2\right] + M_C\left[\left\{\begin{matrix}f\{\alpha\sqrt{(1-k)}\}\\ F\{\alpha\sqrt{(k-1)}\}\end{matrix}\right\}+3/2(1-k)\alpha^2\right] = (wl^2/4)\left[\psi(\alpha)+\left\{\begin{matrix}\psi\{\alpha\sqrt{(1-k)}\}\\ \Psi\{\alpha\sqrt{(k-1)}\}\end{matrix}\right\}+6/(1-k)\alpha^2\right] \quad . \quad . \quad (4)$$

according as k is $<$ or >1.

Thus for a single bay where M_A and M_C are known M_B may be found directly from (4). In such circumstances it would appear unnecessary to seek an approximation for finding the equivalent end load over the whole bay since the more exact solution is relatively simple.

If the axial load kP acts parallel to CA then in place of (4) we should have

$$M_A[f(\alpha)+3/(2-k)\alpha^2]+2M_B\left[\phi(\alpha)+\left\{\begin{matrix}\phi\{\alpha\sqrt{(1-k)}\}\\ \Phi\{\alpha\sqrt{(k-1)}\}\end{matrix}\right\}-3/(2-k)\alpha^2\right] + M_C\left[\left\{\begin{matrix}f\{\alpha\sqrt{(1-k)}\}\\ F\{\alpha\sqrt{(k-1)}\}\end{matrix}\right\}+3/(2-k)\alpha^2\right] = (wl^2/4)\left[\psi(\alpha)+\left\{\begin{matrix}\psi\{\alpha\sqrt{(1-k)}\}\\ \Psi\{\alpha\sqrt{(k-1)}\}\end{matrix}\right\}+12/(2-k)\alpha^2\right] \quad . \quad . \quad (5)$$

according as k is $<$ or >1.

If M_A and M_C are known, then the condition for instability is that the coefficient of M_B should be zero,

$$i.e.,\ \phi(\alpha)+\left\{\begin{matrix}\phi\{\alpha\sqrt{(1-k)}\}\\ \Phi\{\alpha\sqrt{(k-1)}\}\end{matrix}\right\}-3/2(1-k)\alpha^2=0 \quad . \quad . \quad (6)$$

if kP is directed along BA or

$$\phi(\alpha)+\left\{\begin{matrix}\phi\{\alpha\sqrt{(1-k)}\}\\ \Phi\{\alpha\sqrt{(k-1)}\}\end{matrix}\right\}-3/(2-k)\alpha^2=0 \quad . \quad . \quad . \quad (7)$$

if kP acts parallel to CA.

Let α_c be the lowest value of α to satisfy (6) or (7) then

$$\alpha_c=(l/2)\sqrt{(P_c/EI)}$$

where P_c is the corresponding critical load.

$$\text{Thus } P_c=4\alpha_c^2 EI/l^2$$
$$\text{or } P_c=\lambda_c EI/l^2$$
$$\text{where } \lambda_c=4\alpha_c^2.$$

Now the critical load for the whole bay will be given by

$$P_{AC}=\pi^2 EI/l^2$$

and the algebraic mean for the end loads in the two bays will be

$$P_a=\tfrac{1}{2}[P+(1-k)P]$$
$$=(1-k/2)P.$$

Hence the critical value of P in this circumstance will be given by

$$P_{c'} = \{\ 2/(2-k)\ \} \times (\pi^2 EI/4l^2)$$
$$= \text{say } \lambda_{c'} EI/l^2$$
where $\lambda_{c'} = \pi^2/2\ (2-k)$.

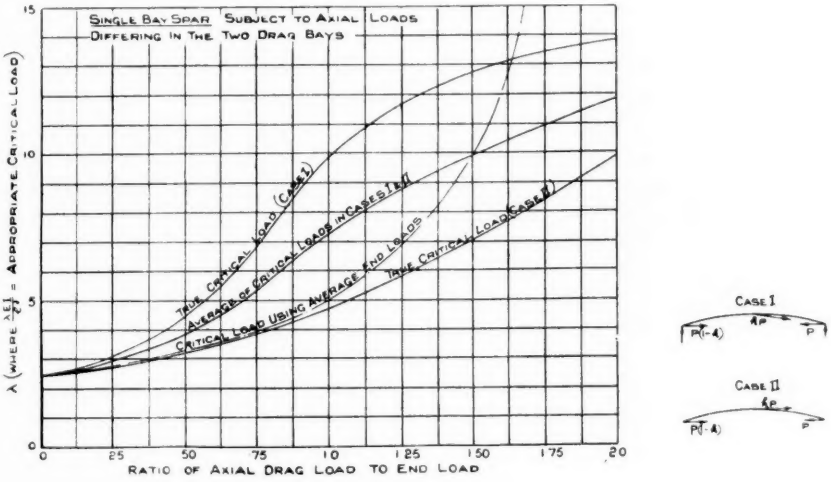


FIG. 2.

In Fig. 2 are plotted

(1) λ_{c1} for Case I where kP is directed along BA.
(2) λ_{c2} for Case II where kP acts parallel to CA.
(3) The average of λ_c for (1) and (2).
(4) $\lambda_{c'}$ which is the critical load for the whole bay on the algebraic mean basis.

Assuming (3) gives the critical load for practical purposes, then we find that the average basis is well on the safe side when the axial load in CB varies between $+P$ and $-.5P$ where P is the compressive load in AB. From the fact that the actual critical load is well above the assumed one in this case, it may be inferred that the average basis provides the more severe condition. Thus when the average basis indicates a very large bending moment the actual maximum bending moment may be comparatively normal.

If M_C is not known, as for instance where the spar is continuous over the centre section and is symmetrical about the vertical centre line of the aeroplane, then we may proceed as follows:—

A second application of the generalised theorem of three moments gives

$$lM_B \left\{ \begin{matrix} f\{\alpha\sqrt{(1-k)}\} \\ F\{\alpha\sqrt{(k-1)}\} \end{matrix} \right\} + 2M_C \left[l \left\{ \begin{matrix} \phi\{\alpha\sqrt{(1-k)}\} \\ \Phi\{\alpha\sqrt{(k-1)}\} \end{matrix} \right\} + l_{cc}\phi(\alpha_{cc}) \right]$$
$$+ l_{cc}M_C f(\alpha_{cc}) - (6EI/l)\,\delta_B$$
$$= (w/4) \left[l^3 \left\{ \begin{matrix} \psi\{\alpha\sqrt{(1-k)}\} \\ \Psi\{\alpha\sqrt{(k-1)}\} \end{matrix} \right\} + l^3_{cc}\psi(\alpha_{cc}) \right]. \quad . \quad . \quad (8)$$

where l_{cc}, α_{cc} refer to the span CC.

δ_B may be eliminated from this equation by the use of (3).

If C were encastre then from the fact that $dy/dx=0$ at C we have

$$M_B \begin{Bmatrix} f\{\alpha\sqrt{(1-k)}\} \\ F\{\alpha\sqrt{(k-1)}\} \end{Bmatrix} + 2M_C \begin{Bmatrix} \phi\{\alpha\sqrt{(1-k)}\} \\ \Phi\{\alpha\sqrt{(k-1)}\} \end{Bmatrix} - (6EI/l^2)\,\delta_B$$

$$= (wl^2/4) \begin{Bmatrix} \psi\{\alpha\sqrt{(1-k)}\} \\ \Psi\{\alpha\sqrt{(k-1)}\} \end{Bmatrix} \quad . \quad . \quad . \quad . \quad (9)$$

according as k is $<$ or >1.

In the single bay case, therefore, where the conditions may be such as to induce a tensile load in the inner half of the bay, it is clear from the foregoing that an exact solution is relatively simple.

In other cases the conditions are not likely to be acute and in general the variation in end load will not be very considerable. In such cases we may with a reasonable expectation of safety assume that the average compressive load may be taken as applying to the whole bay.

ABSTRACTS AND NOTICES

FROM THE

SCIENTIFIC AND TECHNICAL PRESS

Issued by the

Directorates of Scientific Research and Technical Development, Air Ministry

(Prepared by R.T.P.)

No. 30. APRIL, 1934

Aircraft Design, etc.

Ideal Aeroplane Polar Characteristic in Relation to Load Factor. (A. R. Weyl, Z.F.M., Vol. 24, No. 14, 28/7/33, pp. 383-385.) (5.10/27501 Germany.)

Consideration is given to the practicability of " spoiling " the aerodynamic characteristic outside the operating range lying between the maximum horizontal speed and the maximum climbing speed. In this way rigid regulations, imposing load factors for improbable conditions of diving and flattening out, could be met with appreciable saving in structural weight.

Flight Measurements of the Effect of Surface Roughness. (H. Ebert, Z.F.M., Vol. 24, No. 19, 14/10/33, p. 529-532. D.V.L. Report, No. 343.) (5.10/27502 Germany.)

Polar curves of lift drag relations are given for test flights under different conditions—full throttle, zero thrust, and horizontal flight, with different wing fabric finish.

Gliding polars are compared for different types of surface. The highest resistance and lowest lift is shown by an aeroplane with corrugated sheet wing covering, the lowest resistance and highest lift by an aeroplane with highly finished wing and body fabric surfaces, especially at large wing incidence.

The pitch of the airscrew appears to have little influence on the flying resistance.

Influence of Wind on Starting Flight. (G. Mathias, Z.F.M., Vol. 24, No. 17, 14/9/33, pp. 472-3. D.V.L. Report, No. 351.) (5.10/27503 Germany.)

Simple formulæ are found for the influence of wind on the time and length of the starting run.

Pitching Oscillations of an Aeroplane with Free Elevator. (H. Blenk, Z.F.M., Vol. 24, No. 13, 14/7/33, pp. 365-370. D.V.L. Report, No. 334.) (5.102/27504 Germany.)

The equations of motion are formed in the usual way, subject to the condition of a free elevator. Numerical results are obtained for given data and exhibited graphically.

Wind channel experiments lead to slight modifications of the formulæ, in particular the conditions for static stability are more sharply defined, but the conditions for dynamical stability are the same.

Experiments on Longitudinal Oscillations of Aeroplane in a Wind Channel. (R. Seiferth, Z.F.M., Vol. 24, No. 16, 28/8/33, pp. 446-448.) (5.102/27505 Germany.)

The experiments were subject to conditions of elevator spring control. The strength of the spring was determined so that a discontinuous reversal of elevator moment took place on passing through the zero position.

A discussion is given of the possibility of dangerous movements, with free elevator, such as a rapid loop. Rules are given for safe position of the centre of pressure and centre of mass of the elevator.

Six examples of model tests are given graphically, one of which shows dangerously rapid increase of the pitching amplitude. The centre of pressure on the elevator may be seriously displaced by interference and by airscrew wash.

Wind Forces and Moments on a Waterborne Seaplane. (M. Kohler, Z.F.M., Vol. 24, No. 16, 28/8/33, pp. 442-446.) (5.102/7.22/27506 Germany.)

A model seaplane is mounted on a rotatable circular disc let into the floor of a wind channel, the floats being cut away at the water flotation line. The mounting is illustrated by a photograph and by sketches. The velocity field near the plate is explored and shown graphically.

Measurements of forces and moments about axes fixed in the machine were made for the whole range of yawing angle from 0° to 360° and for ranges of pitching and rolling angles. The results are given in numerical tables and graphically and should enable designers to predetermine the seaworthiness in a wind of this type.

Four references.

Air Forces and Moments on a Spinning Model. (M. J. Bamber and C. H. Zimmermann, N.A.C.A. Report, No. 456, 1933.) (5.102/27507 U.S.A.)

A photograph shows the model mounted in a vertical downward stream of air, with the mechanism of the balance exposed to view. A full technical description is given. The results show coefficients of lift, drag and moment for four elevator settings $-27°$ (down) $+3°$, 18° and 33° (up), and for rudder settings from $-40°$ to $+40°$. Change of rudder settings from $+40°$ (with spin) to $+40°$ against spin produced a large yawing moment against the spin with elevator up and about one-fourth the moment with the elevator down.

This was the only control moment produced by the rudder and elevator comparable in magnitude with the yawing moment which maintained the spin.

Fifteen references.

Nacelle-Airscrew Combination. (D. H. Wood, N.A.C.A. Report, No. 462, 1933.) (5.11/27508 U.S.A.)

The effects of position and of cowlings in this, the third of a series of tests, was carried out with the same cowled radial engine mounted in 21 positions relatively to a smaller wing than in the previous tests of this series. Sketches show the dimensions of nacelle and photographs show the 21 positions. The results are tabulated and shown graphically. Cowlings (fixed into the wing) are more effective than changes of position.

The cowled engine should be fitted immediately in front of the wing. Further improvements are obtained by fairing the cowling into the wing, etc.

Seven references.

Influence of Airscrew on Wing. (C. Ferrari, L'Aerotecnica, Vol. 13, No. 8, Aug., 1933, pp. 989-996.) (5.11/27509 Italy.)

The elements of the circulation theory of wing lift and drag are applied and expressions are formed for the influence of the airscrew. Numerical coefficients are introduced from model tests and the effects on lift and drag are calculated. The semi-empirical results thus obtained show close agreement with direct measurements. Lift and drag measurements are made on a trapezoidal model wing (Göttingen No. 420) behind an airscrew (Turin No. 23) driven by an electric motor.

Mutual Influence of Wings and Airscrew. (C. Wieselsberger, Abhandlungen aus dem Aerodynamischen Institut an der Technischen Hochschule, Aachen, No. 13, 1933, pp. 1-11.) (5.11/27510 Germany.)

Consideration is given to the case where the wing is outside the airscrew wake, either above or below. The usual simplifications are made and the distribution of downward induced velocity along the span is expressed by an integral which is evaluated numerically or graphically.

The results are applied to calculate the polar curve of lift and drag. The lift drag polars are plotted for wing above and wing below the wake. Close agreement is obtained between calculation and experiment by suitable choice of semi-empirical coefficients.

The elementary mathematical transformations involved are collected in an appendix.

Effect of Turbulence on Wing Characteristics. (B. Randisi, L'Aerotecnica, Vol. 13, No. 7, July, 1933, pp. 867-889.) (5.11/27511 Italy.)

Reference is made to the effect of turbulence on the resistance of a sphere, and the application of the latter as a standard of turbulence.

A systematic series of measurements of wing characteristics with a transverse wire set before the leading edges is given graphically. For certain positions of the wire the sharp drop of the lift curve is flattened out beyond the stalling point, a matter of importance in avoiding autorotation and spinning instability.

Four references.

Influence of Body and Housings on Wing Qualities. (J. Vladea, Z.F.M., Vol. 24, No. 20, 28/10/33, pp. 555-558, Report of Aerodyn. Inst., Aachen.) (5.11/27512 Germany.)

Following J. Lotz, discontinuous distributions for lift or circulation are expressed in Fourier Series satisfying the Dirichlet condition.

An application of the method is worked out in some detail for wing and body, and for wing, body and housings, and the numerical results are shown graphically for six or seven angles of incidence. Polar curves of lift-drag relations are also given.

Two references.

Relative Loading on Biplane Wings. (W. S. Diehl, N.A.C.A. Report, No. 458, 1933.) (5.112/27513 U.S.A.)

The mathematical methods of Betz, Fuchs, Munk and others, for the determination of the distribution of air, velocity and pressure over the lifting surfaces of a biplane are collected in expositional form and a large number of curves are drawn which enable the designer to read off numerical values of the numerous expressions involved.

A schedule of procedure is given to facilitate numerical computations and a numerical example is worked out.

Fifteen references.

Aero Exhibition, Paris, 1932. (F. N. Scheubel, Z.F.M., Vol. 24, No. 13, 14/7/33, pp. 353-358.) (5.14/27514 Germany.)

A brief account is given of developments and tendencies shown by the exhibits. The principal characteristics of 70 aeroplanes and 69 engines are given in tabular form.

Technical Report on the Flights Round Germany, 1933. (Leander, Z.F.M., Vol. 24, No. 20, 28/10/33, pp. 549-555.) (5.14/27515 Germany.)

The scheme of classification is given and points awarded for each of five selected qualities. Seventy-five machines completed the flight and obtained from 99.5 per cent. down to 26.5 per cent. of the full marks, the details being tabulated. Forty-one machines fell out for various reasons which are shown in a table.

About forty types were represented. The power of individual engines varied from 20 h.p. to 155 h.p. Nearly every large German town was included in the circuit.

Decrease of Wing Lift in Relation to Drag. (J. Stüper, Z.F.M., Vol. 24, No. 16, 28/8/33, pp. 439-441.) (5.20/22.6/27516 Germany.)

Investigations into the partly laminar, partly turbulent, boundary layer are discussed and applied to modify the mathematical theory of Joukowski by introducing resistance in the boundary layer. The point at which laminar flow over a profile changes into turbulent flow is shown graphically for ranges of relative wind speed and incidence on upper and lower surfaces. The methods are necessarily semi-empirical, but they put wing design on as systematic a basis as is possible.

Six references.

Theoretical Determination of Wing Characteristics. (A. Betz, Z.F.M., Vol. 24, No. 16, 28/8/33, pp. 437-439.) (5.20/22.4/27517 Germany.)

Reference is made to developments of Joukowski's methods for profiles which are not immediately transformable to a circle, in particular by development in Fourier series and to mathematical and experimental work on laminar and turbulent boundary layers. Boundary layer relations are given graphically.

Nine references.

Trend of Wing Characteristics. (J. v. Koppen, Z.F.M., Vol. 24, No. 18, 28/9/33, pp. 505-510.) (5.20/27518 Germany.)

The change of plan form from practically rectangular wings to the highly tapered trapezoidal wings of modern German aeroplanes is also visible in the tailplane and rudder.

Stability characteristics and control are discussed and characteristic curves of moments are exhibited graphically as functions of lift. Damped pitching oscillations under different conditions are also shown graphically. The characteristics near stalling speed are discussed separately in relation to safe landing speeds.

Characteristics of 78 Related Aerofoils. (E. N. Jacobs, K. E. Ward and R. M. Pinkerton, N.A.C.A. Report, No. 460, 1933.) (5.20/22.4/27519 U.S.A.)

The sections or profiles are shown in sketches and numbered, and the lift, drag and moment are given graphically and to some extent in tables, and confirm the superiority in aerodynamic quality of wings with moderate thickness and camber.

Systematic conclusions are given in 16 paragraphs as to effect of thickness and camber on the wing characteristic.

Seventeen references.

Pressure Distribution over Twenty Aerofoils in Potential Flow. (I. E. Garrick, N.A.C.A. Report, No. 465, 1933.) (5.20/22.4/27520 U.S.A.)

The aerofoil sections are numbered in reference to published U.S.A., English and German specifications. The pressure distribution is given for four values of the lift coefficient 0, 0.5, 1.0 and 1.5. Corrections for aspect ratio and for ratio to speed of sound are facilitated by tables of parameters worked out numerically.

Thirteen references.

Wing Profiles Near the Ground. (J. Ackeret, Z.F.M., Vol. 24, No. 16, 28/8/33, p. 442.) (5.20/27521 Germany.)

The introduction of a flat board in a wind channel to represent the ground produces serious disturbances. The method of testing two models in mirror image positions is better. Towing experiments are correct in principle.

Measurement of Deformation of Wings. (Guerbilsky (summarised by P. Léglise), L'Aéron., No. 166, March, 1933, pp. 58-69.) (5.25/27522 France.)

The method is exhibited by depositing a strip of graphite 1.5 mm. thick on a wooden rule. The resistance of the graphite in the unstrained state is about 50,000 ohms, and varies with bending strain. The strip is connected to a neon tube oscillograph in a modulated circuit.

The variation in resistance is obtained by bending the rule to either side, imposing compression or extension on the graphite strip. A figure shows the calibration of proportional changes of resistance against strain. The relation is approximately linear.

An installation for application of the method to wings was exhibited.

The Strength of Wings with Rigid Covering. (P. Bodet, L'Aérophile, No. 11, Nov., 1933, pp. 336-338, and No. 12, Dec., 1933, pp. 364-365.) (5.252/27523 France.)

The author deals with combined shearing and bending force. The method of minimum work is applied to the strain energy in spars and covering.

Analytical expressions are worked out in considerable detail. No numerical applications are given.

Airscrews

Tests of Six Airscrew Sections. (J. Stack, N.A.C.A. Report, No. 463, 1933.) (5.60/27524 U.S.A.)

A description of the channel and accessories is given, with illustrations and calibration figures. The sections are based on R.A.F. and Clark Y sections, with the thickness increased by factors increasing towards the hub.

The effects at high lift speeds of the compressibility of the air are plotted. Generally speaking, the lift coefficients rise to a critical ratio between top speed and speed of sound, which is defined with some sharpness, and then fall abruptly, the critical range being 0.5 to 0.8 of the speed of sound, but there are some anomalous cases lying outside the range. The drag coefficients increased slightly up to the critical value and then steeply.

Comment is made on attempts to establish a mathematical physical theory of the effects of compressibility and it is concluded that they must fail near and above the critical ratio.

Nineteen references.

Thrust and Torque of Adjustable Pitch Metal Airscrew. (E. P. Hartman, N.A.C.A. Report, No. 464, 1933.) (5.64/27525 U.S.A.)

The characteristics are plotted against V/nD for the positive range and against nD/V for the negative range, for a range of blade angle settings measured at .75 radius from $-23°$ to $22°$ and for different positions of engine nacelle. Below $7°$ blade angle, engine power is required to give maximum drag in a glide.

Numerical examples are given to illustrate possible uses of the controller pitch, in particular for air braking.

Seven references.

Lifting and Propelling Paddle Wheels. (C. B. Strandgren, L'Aéron., No. 172, Sept., 1933, pp. 81-88.) (5.643/27526 France.)

Blades, set round a wheel, feather so as to maintain flying incidence. The kinematical relations are worked out and are illustrated by six diagrams. The aerodynamical relations are expressed as integrals round a cycle and involve approximate assumptions as to mean lift with variable relative velocity and incidence. Mutual interference raises a further and highly intractable problem.

Three photographs show the paddle wheel actually constructed and the photographs show a Strandgren machine with a pair of paddle wheels under stationary test and a Moineau machine in the field.

Experiments on Wing Profiles in Circular Grid Formation. (F. Numachi and I. Masuko, Ing. Arch., Vol. 4, No. 5, Oct., 1933, pp. 470-480.) (5.643/27527 Germany.)

The main object of the experiments is the study of flow through the guide vanes of water turbines of the propeller type. The inclination of the vanes can be altered relatively to the radial water flow and the pressure distribution over the vane is recorded.

The number and angular setting of the vanes was varied over wide limits. At a small negative incidence ($-5°$) there was least interference and the flow did not vary appreciably when the number of vanes varied from 4 to 12.

Eight references.

Aerodynamics—Autorotation. (Riabouchinsky (summarised by P. Léglise), L'Aéron., No. 166, March, 1933, p. 55.) (5.644/27528 France.)

A fan with two blades of zero pitch set in rotation continues to rotate, while guide vanes mounted freely behind the fan rotate in the opposite direction.

Instruments

Instrument for Measuring and Recording Seaway. (Z.V.D.I., Vol. 77, No. 27, 8/7/33, p. 755.) (6.24/27529 Germany.)

A pressure recording device is suspended below a floating buoy. The pressure fluctuations are a measure of the surface motions of the buoy.

Influence of Ship Form on Motion in a Seaway. (G. Weinblum, Werft-Reederei-Hafen, Vol. 14, No. 19, 1/10/33, pp. 269-275, and No. 20, 15/10/33, pp. 289-292.) (6.24/27530 Germany.)

The problem being one of forced oscillations the quantities involved are the ship's dimensions, moments and products of inertia, the metacentric height and the applied forces. The natural periods of rolling, pitching and immersion are determined in the usual way, along with the periodic forces applied by waves of specified height, length and velocity. Non-dimensional parameters are constructed, analytical expressions are formed and their mutual relations are computed. The results are tabulated and shown graphically in families of curves, each curve corresponding to a given instant in the cycle.

In Part II, the effect in a seaway of ship's form, particularly of the fullness factor, is discussed and curves of immersion and pitching oscillations are calculated on approximate assumed data. A differential equation is formed for forced oscillations and is discussed by the usual methods. Numerous numerical results are given in tables and in graphical charts showing families of curves giving the relation between the angular displacement and lever arm for different ratios of free-board, beam and draught. The fundamental result is given in a diagram showing the effective lever arm under varying conditions. Within a certain shaded area of the diagram abrupt changes of the amplitude may occur.

Twelve references.

A New Micromanometer. (Z.V.D.I., Vol. 77, No. 37, 16/9/33, p. 1019.) (6.251/27531 Germany.)

Particulars are given of a simple form of bubble manometer using a single liquid and reading to .01 mm. water.

A New Indicator for High Speed Engines. (F. Schmidt, Z.V.D.I., Vol. 77, No. 27, 8/7/33, pp. 748-749.) (6.252/27532 Germany.)

A pressure balance method is employed, as in the Farnborough instrument. When a prescribed pressure is exceeded a diaphragm closes a circuit containing a neon lamp, which operates with the minute current of 10-20 m.-amps with relatively small time lag in comparison with the lag in the Farnborough inductive circuit. The lamp is focussed on a strip of sensitised paper carried by a rotating drum attached to the shaft and slides along it in proportion to the imposed pressure. Each exposure prints a narrow strip and the strips overlap and build up a composite indicator diagram for a large number of cycles. The pressure is controlled by a pressure chamber with a small orifice which produces a slow pressure drop from above the maximum cylinder pressure to atmospheric pressure.

The overlap of successive strip records appears to mask irregularities of firing. This could be improved by opening the scale of the sliding displacements along the shaft.

Combined Mechanical-Optical Speed and Power Meter. (P. Müller, Z.V.D.I., Vol. 77, No. 28, 15/7/33, p. 758.) (6.271/27533 Germany.)

A transmission dynamometer gives direct power readings by inter-gearing the torque spring with a centrifugal pendulum responding to the speed of rotation. The combined deflection is observed optically.

A Balloon Compass. (P. Perlewitz, Z. Instrum., No. 7, July, 1933, pp. 330-331.) (6.501/27534 Germany.)

A transparent compass card of 17 mm. diameter is attached to the magnetic needle, the total weight of the moving parts being 0.9 gm. The time of a half oscillation is about 1 second. The instrument is intended for drift observation and for this purpose is mounted in a vertical pocket of a small telescope, which in operation is held horizontally. A system of prisms projects the observed land or astronomical mark into the field of view, along with a section of the card illuminated from below. The complete instrument weighs less than 4lb.

Determination of Wind Drift in the Aeroplane without Ground or Astronomical Observations and without the Use of Wireless. (P. Raethjen, Luftwacht, No. 10, Oct., 1933, pp. 313-316.) (6.51/27535 Germany.)

The drift is determined relative to cloud banks possessing some characteristic feature. The motion of the bank relative to the ground has to be determined separately. Examples are given of successful drift determination from two cloud banks.

The "Crocco" Incidence Indicator. (A. Gigli, L'Aerotecnica, Vol. 13, No. 8, Aug., 1933, pp. 1012-1020.) (6.54/27536 Italy.)

A "Krell" capsule has the general form of a pitot head, but has two orifices diametrically opposite in the side of the tube. The tube is pivoted on the leading edge of the wing with the orifices in the plane of symmetry and is capable of rotation through $\pm 50^\circ$ in that plane about a hinge in the leading edge of the wing.

For each wing incidence the "Krell" head is rotated until zero differential reading between the pressures at the two orifices is noted. The angle of rotation is a direct measure of the angle of incidence.

Calibration curves are reproduced.

Altitude Hysteresis of a Valve Generator. (H. Löwy, Phys. Zeit., Vol. 34, No. 19, 1/10/33, pp. 730-731.) (6.64/27537 Germany.)

An instrument is described for determining height by variable capacity. A diagram of the circuit shows a variable capacity in a circuit with a single valve with oxide cathode. The decrease of capacity rate with height is over compensated by increase of current rate with decreasing capacity. This effect depends on the hysteresis loop in the current capacity characteristic and the adjustment is made so that the capacity at a selected height is just above the lower branch of the hysteresis loop.

In a calibration test flight in a Zeppelin the height selected was 250 metres, at which no current flowed. Up to 350 metres the current rose continuously from zero to 90 m.-amps, after which the circuit became unstable. A range from 100 m. to 200 m. could be selected in practice.

Pressure Head Statoscope. (L. Scriba, Flugsport, Vol. 25, No. 21, 11/10/33, pp. 450-452.) (6.67/27538 Germany.)

It is stated that the statoscope, which indicates slow changes of static pressure, is erratic in recording. The new instrument records slight changes in the velocity pressure head and thereby slight changes in incidence.

It has been used in glider flight and the claim is made that it is useful for controlling the height in blind flying.

A photograph shows the connections with pressure head, air chamber and recording instrument.

Aircraft Flight

Extension of Theory of Lateral Instability with Numerical Examples. (G. Matthias, Z.F.M., Vol. 24, No. 19, 14/10/33, pp. 527-529, and No. 20, 28/10/33, pp. 563-568. D.V.L. Report, No. 350.) (7.20/27539 Germany.)

The author emphasises the simplification of the analysis by the introduction of non-dimensional parameters (Aeronautical Glossary, 1921). The analysis follows the usual lines. In numerical examples the lines of demarcation, between statically stable and unstable regions are shown graphically in three diagrams for groups of three parameters, in which the position of the centre of lift is always in evidence. The delimitations between regions of dynamical stability and instability are more complicated and are exhibited in eleven diagrams.

The values of the physical coefficients from which the non-dimensional characteristics and coefficients are formed are determined in the usual way from full scale and model data.

Six references.

Manœuvrability of "O3U-1" Observation Aeroplane. (F. L. Thompson and H. W. Kirschbaum, N.A.C.A. Report, No. 457, 1933.) (7.40/27540 U.S.A.)

Two previous investigations have been given (Reports 369 and 386). A photograph of the aeroplane is given and a schedule of performance figures. The methods of test reduction are specified and the results given graphically in 31 charts.

The quantities measured include linear and angular accelerations, under maximum control movements, and in complete manœuvres such as rolling, half loop and Immelman turns.

Eight references.

The Sperry Automatic Gyroscopic Control. (Rev. F. Aér., No. 51, Oct., 1933, pp. 1176-1181.) (7.54/27541 France.)

An illustrated description is given of the "Automatic Pilot" as fitted to the Lockhead "Vega" machine in which Wiley Post did a solo world trip. The installation weighs about 75lbs. Air and oil transmission are applied. An alarm sounds if the aircraft motion becomes unsteady, so that the pilot may release his attention and even obtain some sleep.

One reference.

Engines—Thermodynamics

Glow Plugs for Starting Diesel Engines. (Flugsport, Vol. 25, No. 22, 25/10/33, pp. 479-480.) (8.13/27542 Germany.)

Glow plugs are either single pole or double pole and require 2-3 volts for operation. The heating spiral is made of braided Ni-Cr wire and has a satisfactory life.

Ignition Lag in Diesel Engines. (Autom. Ind., Vol. 69, No. 9, 26/8/33, pp. 248-250.) (8.13/27543 U.S.A.)

Attempts have been made by Kuttner and Rippere to measure ignition lag by recording the time at which the bouncing pin leaves its seat. Apart from the electrical lag of the time recording apparatus there is a possible serious error due to the inertia of the pin itself.

Grading of the Diesel fuels by this method does not agree with the critical compression ratio method of the Co-operative Fuel Research Committee. Further, the C.F.R. engine at high compression ratio does not operate as a representative Diesel engine and gives trouble with fuels which are found suitable for commercial engines. The problem of rating Diesel fuels remains obscure.

Contribution to the Combustion Technique of High Speed Diesel Engines with Precombustion Chamber. (G. Ritz, Autom. Tech. Zeit., Vol. 36, No. 8, 25/4/33, pp. 197-203.) (8.13/27544 Germany.)

The author varied compression ratio, speed, size of precombustion chamber and nature of spray. Indicator diagrams showing ignition delay and maximum pressure were obtained. He concludes that for smooth running the compression ratio should be of the order of 20/1; the precombustion chamber should be as large as possible consistently with this. The spray must be coarse to ensure that preliminary combustion only starts in the chamber. With these precautions good consumption figures can be obtained with maximum explosion pressure below 900lb. per sq. in.

Six references.

Engines—Design and Performance

Definition of Terms as Applied to Aero Engines with Special Reference to High Altitude Engines. (H. Oestrich, Z.F.M., Vol. 24, No. 14, 28/7/33, pp. 393-398. D.V.L. Report 339.) (8.20/27545 Germany.)

Such terms as normal output, maximum output and continuous output when applied to aero engines require precise and accepted definitions. Suggestions put forward by the D.V.L. have received official sanction. An international agreement on these matters is urgently wanted.

New Method of Scavenging Two-Stroke Diesel Engines. (Dr. Ing. Mohr of Krupps (Germaniawerft), Autom. Tech. Zeit., Vol. 36, No. 8, 25/4/33, pp. 203-205.) (8.21/27546 Germany.)

Single piston engines with transverse scavenging retain an exhaust residue which eddies near the cylinder head. The author provides two additional scavenging ports diametrically opposite on an axis at right angles to the usual ports. An additional exhaust port is placed slightly above the usual scavenging port. The three additional ports are of relatively small cross section and do not weaken the cylinder construction.

A model is described which enables the flow to be studied. Engine tests are stated to have given favourable results.

Single Cylinder Test Engine of the D.V.L. (F. Nuffert and W. D. Bensinger, Autom. Tech. Zeit., Vol. 36, No. 15, 10/8/33, pp. 391-392. D.V.L. Report, No. 326.) (8.22/27547 Germany.)

The single cylinder test bed is of robust construction, and will take full size aircraft engine cylinders. The bed plate to which the cylinder is attached can be raised or lowered to give a wide variation of the compression ratio and elaborate arrangements are made to vary the valve timing. Both adjustments can be made under engine load. Air measurements are made by wet gas meter. Supercharging is applied by a Root's blower.

Consideration of Similarity—Applied to the Design of Internal Combustion Engines. (O. Lutz, Ing. Arch., Vol. 4, Aug., 1933, pp. 373-383.) (8.225/27548 Germany.)

By introducing parameters, such as the speed, of dynamically similar engines of 1 h.p. or of 1 litre, characteristics of totally dissimilar engine designs are made immediately comparable, *e.g.*, the variation in heat transmission. This representation exhibits similarities between the characteristics of the Man engines fitted to the battleship " Deutschland " and those of aero engines. It is stated that the Man are developing the high speed ship engine for aeronautical purposes.

The Development of Air-Cooled Engines by the Use of a Separate Blower. (Z.F.M., Vol. 24, No. 15, 14/8/33, p. 426. D.V.L. Report, No. 324.) (8.235/27549 Germany.)

The heat transfer when an air stream from the blower is directed on to the cylinder is greater than when the cylinder is freely exposed to the relative wind; the power absorbed by the blower is less than that absorbed as drag by the exposed cylinder. The heat flow from the head is eight times the flow from the barrel (6 cal./cm.^{2}/sec. and $\frac{3}{4}$ cal./cm.^{2}/sec. respectively).

Tests of a Rateau Centrifugal Supercharger for a 700 h.p. Engine. (H. Oestrich, Autom. Tech. Zeit., Vol. 36, No. 16, 25/8/33, pp. 405-411. D.V.L. Report, No. 325.) (8.235/27550 Germany.)

The supercharger compresses in two stages at a shaft speed of 1,700 r.p.m. with an internal clutch and step-up gear ratio of 12.3. From the illustration

the impeller wheels, approximately 20 cm. in diameter, are housed in a separate casing from the gears. The fan casing space is about 50 cm. diameter by 40 cm. long, the gear casing about the same. No weights are given. At a compression ratio of 2.23, corresponding to an altitude of 6,250 metres, the fan absorbed 110 h.p., showing an adiabatic compression efficiency of 52 per cent.

Three references.

The Henschel-Lanova Diesel Engine. (A. E. Thiemann, Autom. Tech. Zeit., Vol. 36, No. 8, 25/4/33, pp. 206-207.) (8.25/27551 Germany.)

The Lanova engine has two horizontal chambers in series communicating with the combustion space through a relatively large hole. Injection takes place early in the stroke, through a nozzle diametrically opposite the chamber and the spray thus has to traverse the whole of the annular combustion space before it can enter. High injection pressures (1,200lb. per sq. in.) are combined with a low compression ratio (12/1).

The design utilised a floating wet liner and the provision for stiffness is ample. A centrifugal oil cleaner is fitted. Specific weight is about 15 h.p. for a six-cylinder of 100 h.p. engine.

One reference.

Diesel Engine Design Development. (P. M. Heldt, Autom. Ind., Vol. 69, No. 10, 2/9/33, pp. 279-280.) (8.25/27552 U.S.A.)

Increased Diesel engine speeds are obtained by controlling flow of fuel in pipe lines so as to avoid pressure surges and maintain definite injection periods free from dribble. Injection engines with spark ignition are liable to carbon formation and crankcase oil dilution.

The Daimler-Benz 700 h.p. Aircraft Diesel Engine. (Autom. Tech. Zeit., Vol. 36, No. 8, 25/4/33, p. 209.) (8.25/27553 Germany.)

The engine has 12 cylinders in V, bore 165 mm., stroke 210 mm., and a precombustion chamber. It develops 700 h.p. at 1,675 r.p.m. giving a volume output of 13 h.p. per litre. The specific weight is just under 3lb. per h.p. A 1.7/1 reduction gear is fitted. Ball and roller bearings are extensively used for the crankshaft and needle bearings for the valve rockers.

The Man 100 h.p. Light Weight Diesel. (Autom. Tech. Zeit., Vol. 36, No. 8, 25/4/33, p. 205.) (8.25/27554 Germany.)

The engine has six cylinders of 120 mm. bore and 180 mm. stroke and develops 100 h.p. at 1,400 r.p.m. There is direct injection, combined with mixing in an auxiliary air chamber near the jet, communicating with the combustion chamber through a set of small holes. Air taken into the mixing chamber passes into the main combustion chamber during the following expansion stroke. There is no combustion in the air chamber such as takes place in the precombustion chambers of certain types of engines.

The manufacturer attained an engine weight of 15lb. per h.p. by welded steel construction.

The Ganz-Jendrassik Lorry Diesel Engine. (K. Danninger, Autom. Tech. Zeit., Vol. 36, No. 8, 25/4/33, pp. 207-209.) (8.25/27555 Germany.)

The engine has a precombustion chamber of large capacity and a recessed piston crown into which the flame projects. The fuel pump has a spring trigger action which maintains high plunger speeds at low engine r.p.m. Variable inlet valve timing throttles the air at starting.

The Influence of Pressure on Spontaneous Ignition of Inflammable Gas-Air Mixtures. I. Butane-Air. (D. T. A. Townend and M. R. Mandlekar, Proc. Roy. Soc., Vol. 141, No. 844, 1/8/33, pp. 484-493.) (8.28/27556 Great Britain.)

The ignition temperature of butane mixtures as determined by the Mallard and Le Chatelier method undergoes a fall with increases of pressure, especially in the neighbourhood of a critical pressure. The effect of ethyl lead in raising the ignition temperature is practically confined to the critical region. It is suggested that intermediate oxidation products are formed in confirmation of the Bone hydroxylation theory. No peroxides were discovered.

Spontaneous Ignition Temperature of Inflammable Gas-Air Mixtures. Part II—Pentane. (D. T. A. Townend and M. R. Mandlekar, Proc. Roy. Soc., Vol. 143, No. A.848, 4/12/33, pp. 168-176.) (8.28/27557 Great Britain.)

The ignition temperature of pentane depends on mixture strength and pressure. An increase of pressure always lowers the ignition temperature. The effect is disproportionately large for certain mixture strength and for a pressure between 1 and 3 atmospheres. At higher pressures the effect is small and continuous.

The effect of tetra-ethyl lead is to raise the critical pressure. The phenomenon appears to be connected with the formation of intermediate products which require further study.

Seven references.

Measurement of Auto-Ignition Temperature in High Speed Internal Combustion Engines. (K. Schnauffer, Z.V.D.I., Vol. 77, No. 34, 26/8/33, pp. 927-931.) (8.28/27558 Germany.)

An electrically heated glow electrode of nickel steel is placed in the combustion chamber along with the sparking plug. Ignition is recorded by ionisation currents produced by the flame. Auto-ignition with the spark cut off is thus clearly indicated even when the resulting explosion is too weak to operate the engine.

Experiments were conducted with petrol, benzol and mixtures of the two (50 per cent.). The auto-ignition temperatures did not vary by more than 40°C. for the two extremes, being of the order of 900, 940 and 920°C. Testing in the laboratory by the ignition pot method, the auto-ignition temperatures are of the order of 300°C. for petrol and 600°C. for benzol.

The higher readings in the engines are connected with the shorter lag required to ensure ignition near dead centre. The presence of exhaust residue also increases the auto-ignition temperature in this case.

Variation in Ignition Timing and Shape of Voltage Curve as Revealed by the Cathode Ray Oscillograph. (H. Viehmann, Autom. Tech. Zeit., Vol. 36, No. 17, 10/9/33, pp. 426-430. D.V.L. Report, No. 335.) (8.28/27559 Germany.)

A comparison between the voltage curves of a coil and magneto ignition system shows general similarity. The time interval between break of primary and breakdown of spark gap (generally reached at 6,000 volts) varies between 10^{-4} and 1.5×10^{-4} seconds for each system. Variations in power with the two systems were traced to the contact breaker, which gave appreciable differences in time of break for the same mechanical setting when the engine was operating at speed.

Four references.

Engines—Design and Strength of Components

Light Alloy Pistons for Internal Combustion Engines. (E. Mahle, Werft-Reederei-Hafen, Vol. 14, No. 18, 15/9/33, pp. 255-256.) (8.32/27560 Germany.)

Various forms are shown of alloy pistons from 100 to 200 mm. diameter for ships' Diesel engines. Accuracy of workmanship and good surface finish are essential for successful operation.

Influence of Firing Order on the Torsional Vibration of In-Line Engines. (M. Scheuermeyer, Autom. Tech. Zeit., Vol. 36, No. 16, 25/8/33, pp. 401-404, and No. 17, 10/9/33, pp. 431-433.) (8.36/27561 Germany.)

In the usual calculation for vibration frequency, one half of the reciprocating masses is assumed to participate in the vibration. The assumption leads to a mean frequency. Actually the varying acceleration of the masses imposes considerable variation in frequency during a revolution.

The author shows how these variations can be minimised by altering the firing order. The secondary harmonics can be eliminated, but the principal harmonics operate over an increased range.

Six references.

The Friction Vibration Damper. (G. Jendrassik, Z.V.D.I., Vol. 77, No. 37, 16/9/33, pp. 1009-1012.) (8.36/27562 Germany.)

Elementary dynamical principles are discussed and rules for design are given. With properly dimensioned parts adequate damping is maintained over a wide range of variation in the coefficient of friction.

Free Vibrations and Critical Speeds of Shafts and Spars. (C. Minelli, L'Aerotecnica, Vol. 13, No. 8, Aug., 1933, pp. 997-1011.) (8.36/27563 Italy.)

From the form of the differential equations conditions for dynamical similitude are formed and an analogy is drawn between the conditions for dynamical similitude in bending and in torsion.

Radially and Axially Loaded Ball Bearings with Large Number of Balls. (A. Meyer, Z.V.D.I., Vol. 77, No. 37, 16/9/33, p. 1018.) (8.37/27564 Germany.)

In a double row ball bearing the usual cage is replaced by an intermediate row of distance balls held by a tension ring. The bearings are in production with satisfactory results.

One reference.

Engines—Cooling

Heat Transfer Phenomena in Boiling Water. (Z. Instrum., No. 7, July, 1933, p. 298.) (8.40/27565 Germany.)

Determinations were made at the Reichsanstalt on the heat transfer coefficient between steam bubbles and the surrounding liquid. At the instant of bubble formation the flow of heat is about 4 calories per cm.^{2} per sec. per 1°C., a remarkably high figure which falls to less than 0.3 by the time the bubble reaches the surface.

Instruments for Measuring Heat Transfer. (Z.V.D.I., Vol. 77, No. 26, 1/7/33, p. 719.) (8.40/27566 Germany.)

A brief note is given on the general problem. Reference is made to an exploring thermo-couple in a spherical case, the time for a temperature rise from 300° to 400° being noted by stop watch.

A flat cylindrical housing is described and illustrated by side and plan sketches and is more convenient for measuring heat transfer at flat surfaces.

Jacket Heat of High Speed Internal Combustion Engine. (E. Drucker, Z.V.D.I., Vol. 77, No. 33, 19/8/33, pp. 912-913.) (8.40/27567 Germany.)

The thermal loading of the jacket is defined as the rate of heat loss divided by the surface of the cylinder exposed to hot gases at mid-stroke. This factor increases nearly linearly with piston speeds above 3 m. per sec. and more steeply at lower speeds. There is a general similarity between Diesel and carburettor engines.

Seven references.

The Development of Air-Cooled Engines with Separate Fan Cooling. (R. Lohner, Autom. Tech. Zeit., Vol. 36, No. 14, 25/7/33, pp. 351-357, and No. 15, 10/8/33, pp. 375-383. D.V.L. Report, No. 324.) (8.42/27568 Germany.)

The blast from a fan is directed by guides over the hottest parts of the cylinder. This controlled cooling gives greater reliability and allows of larger cylinders than is feasible with cooling by the undirected slipstream.

This factor is more important to the designer than reduction in head resistance and in the power lost in cooling the engine.

Four references.

Engines—Lubricants and Lubrication

The Viscosity and Congealing of Lubricating Oils. (M. Bourdiol, Pub. Sc. et Tech., No. 27, 1933.) (8.50/27569 France.)

A simple form of viscosimeter is supplied with air at variable pressure to drive the oil through the capillary tube. Accurate measurement of small deliveries is attained by displacement of a solution of calcium chloride in a second capillary tube.

Measurements of castor and mineral oils extended over the temperature range $-20°$ to $30°$. It is easy to prevent castor oil from freezing at $-20°$, at which temperature its viscosity is considerably less than that of most mineral oils.

The process of congealing was observed by microscope. With decreasing temperature certain stearides first separate out and act as nuclei for subsequent congealing. If these stearides are removed the liquid state remains relatively stable down to $-20°$C.

Oxidation Resistance of Lubricating Oils. (Autom. Tech. Zeit., Vol. 36, No. 14, 25/7/33, p. 367.) (8.54/27570 Germany.)

The stability of the oil is judged by the acidity before and after treatment with hydrogen peroxide. Vegetable oils are completely modified and form jellies.

Lubrication of Diesel Engines, Especially Ships' Engines. (E. Goos and K. Krekeler, Z.V.D.I., Vol. 77, No. 30, 29/7/33, pp. 828-830.) (8.58/27571 Germany.)

The high speed double acting two-stroke engine leads to corresponding reduction in weight of engine plant and in space occupied. Specific weights have decreased from 250 to 15lb./h.p., and the overall length of a 3,600 h.p. has diminished from 40ft. to under 10ft. The compact construction has led to lubrication difficulties. It is necessary to use oils which leave little residue, especially when lubricating the piston. A high viscosity oil, refined with SO_2 is recommended and this oil should be introduced in carefully metered quantities at distributed points. The piston lubrication is thus kept separate from that of the rest of the engine for which low viscosity oil is introduced through the crankshaft in the usual manner. If the lubricating oil is to be used for piston cooling a highly refined low viscosity oil free from deposits is required.

Oil Consumption. (Autom. Ind., Vol. 69, No. 9, 26/8/33, pp. 232-236.) (8.58/27572 U.S.A.)

Oil rings built up from several pieces are effective in reducing oil consumption and formation of carbon. A dry sump engine installation is described in which measurements of oil consumption with different oils can be rapidly carried out.

Engines—Fuels

Ethyl Alcohol as a Motor Fuel. (K. R. Dietrich, Autom. Tech. Zeit., Vol. 36, No. 20, 25/10/33, pp. 519-520.) (8.606/27573 Germany.)

Objections to ethyl alcohol are low calorific value, poor starting quality, hygroscopic nature and corrosive properties.

Blends with petrol and benzol are largely free from these defects. The following blend is in general use in Germany:—

	% by weight.
Alcohol	15
Benzol	40
Petrol	45

Experiments on aircraft with this fuel are in progress.

Two references.

The Suitability of Various Fuels for the Starting of Engines. (Prof. Wawrziniok, Autom. Tech. Zeit., Vol. 36, No. 18, 25/9/33, pp. 464-469, and No. 19, 10/10/33, pp. 496-499.) (8.649/27574 Germany.)

The starting quality largely depends on the vapour pressure and the latent heat of the fuel. Mixtures of alcohol and petrol may have a higher vapour pressure than that of either constituent by itself. Cold mixtures with high latent heat require intense ignition sparks.

Fourteen references.

Engines—Injection and Exhaust Systems

The Injection Problem of the Diesel Engine, with Special Reference to Operative Speed Range. (R. Retel, L'Aéron., No. 173, Oct., 1933 (Supplement), pp. 93-105.) (8.705/27575 France.)

The operation over a speed range of the compression ignition engine with airless injection is largely a question of fuel pump characteristics. Efficient operation over a wide speed range is difficult, a serious disadvantage in comparison with the carburettor.

Penetration and Duration of Fuel Sprays for a Pump Injection System. (A. M. Rothrock and E. T. Marsh, N.A.C.A. Report, No. 455, 1933.) (8.705/22.2/27576 U.S.A.)

A diagrammatic sketch shows the general arrangement of the photographic apparatus and pump. Details are shown in sectioned sketches. Specimen films are reproduced showing the stem lift of the injection valve and the growth of the jet. The numerical results are shown in twelve graphical charts, which give penetration as a function of initial pressure and time.

Five references.

Photomicrographic Studies of Fuel Sprays. (D. W. Lee and R. C. Spencer, N.A.C.A. Report, No. 454, 1933.) (8.705/22.2/27577 U.S.A.)

Seventy-five instantaneous photographs of jets and sprays are reproduced, under injection pressures varying from $1\frac{1}{2}$ to 280 atmospheres and chamber pressures varying from 0.0013 to 14 atmospheres.

Photographs taken with high magnification show short lengths of jet at different distances from the nozzle, while those with low magnification show considerable lengths of jet. The latter give a general view, the former more detail. The break up of the jet takes a large number of different intermediate forms, knowledge of which is essential for discussion of ignition and combustion.

Twelve references.

Acoustical Theory of Exhaust Silencers with Perforated Baffle Plates. (A. H. Davis, Phil. Mag., Vol. 16, No. 107, Oct., 1933, pp. 787-793.) (8.721/27578 Great Britain.)

The elementary theory of resonators in series is applied to a silencer with perforated baffle plates and approximate expressions are found, which indicate the suppression of all but low pitch sounds.

No quantitative experimental results are available for a comparison, but qualitative observation appears to confirm the general conclusion.

Measurement of Power Available in Engine Exhaust. (C. Waseige, L'Aéron., No. 171, Aug., 1933, p. 189.) (8.722/27579 France.)

The author is of the opinion that the utilisation of exhaust energy in a turbine is more than offset by the increased back pressure. An experimental layout is described for measurement of the factors entering into the problem.

Engines—Pumps

Performance of Oil Pumps. (E. W. Steinitz, Z.V.D.I., Vol. 77, No. 29, 22/7/33, pp. 785-788.) (8.743/27580 Germany.)

The importance of centralised lubrication for prime movers, machine tools, etc., has been recognised in Germany for years. Oil pumps of great reliability have been produced. Selected designs are described and illustrated showing tell-tale arrangements for visual indication of oil flow. The old tube indicator in which the oil on its delivery passes through a water plug still holds first place for reliability and safety.

Reference is made to grease lubrication from a central pumping plant.

Engines—Gears, Couplings, etc.

The Wear of Toothed Wheels. (M. Fink, Z.V.D.I., Vol. 77, No. 36, 9/9/33, pp. 978-979.) (8.761/27581 Germany.)

Initial stages of wear are associated with oxidation of the material by oxygen dissolved in the oil, even when the gear wheels are totally immersed. The author states that a graphite emulsion in the oil forms a protecting layer which reduces oxidation.

Nine references.

Sandner Hydrostatic Coupling. (W. Allerding, Werft-Reederei-Hafen, Vol. 14, No. 17, 1/9/33, pp. 242-244.) (8.765/27582 Germany.)

The internal primary and external secondary are coaxial. Gear wheels are mounted round the periphery of the secondary, in mesh with a single central gear wheel mounted on the primary. Load on the primary sets the secondary gear wheels in rotation on their own axes, under which they act as oil pumps

and set up a back pressure, bringing them to rest relatively to the secondary, which then receives a direct drive.

Relief valves in the pumping circuits are set to release the pressure when it exceeds a value corresponding to the maximum permissible load. The secondaries then rotate on their axes against high damping faces. Sketches and photographs show the simple general arrangement.

Armament

Firing Control of Anti-Aircraft Batteries. (A. Kuhlenkamp, Z.V.D.I., Vol. 77, No. 35, 2/9/33, pp. 949-952.) (9.11/27583 Germany.)

American practice is described. Regret is expressed that the Versailles Treaty forbids such weapons to Germany.

Armament. (P. Léglise, L'Aéron., No. 166, March, 1933, p. 59.) (9.11/27584 France.)

A small cannon is shown mounted on a light tripod, discharging a projectile from one end and burnt gases from the other end. The stability of the mounting indicates very complete compensation of the recoil.

Aerodynamics—Instability of (Streamline) Projectiles. (Riabouchinsky (summarised by P. Léglise), L'Aéron., No. 166, March, 1933, p. 55.) (9.16/27585 France.)

A streamline model which has a surface of rotation is mounted on an axis passing through the centre of gravity at right angles to the axis of rotation. It takes up a motion of autorotaion from any position at rest.

Aerodynamics of an Arrow. (G. J. Higgins, J. Frank. Inst., Vol. 216, No. 1, July, 1933, pp. 91-101.) (9.16/27586 U.S.A.)

The drag coefficient is taken as constant over any slight changes in orientation during flight. A trajectory is determined for measured values of the physical quantities involved and is shown graphically. The initial velocity is 180ft. per sec., the range 650ft., highest point of flight nearly 200ft.

An approximate formula is fitted closely to the observed trajectory by adjustment of the coefficients. The effect of changes in the physical quantities is also shown graphically.

Two references.

New System of Mapping Field of View. (M. Jannin, L'Aéron., No. 172, Sept., 1933, pp. 214-215.) (9.17/27587 France.)

The meridians become sine curves with equally spaced amplitudes, and the circles of latitude equi-distant straight lines. The transformation is not conformal, but equality of small corresponding areas is maintained. The hemisphere projects into the section of an oblate ellipsoid.

Representations of the field of view of four machines are reproduced.

Concentration of Bomb Hits from a Flying Formation. (E. Lanciani, Riv. Aeron., No. 6, June, 1933, pp. 373-388.) (9.33/27588 Italy.)

A sketch shows a formation of three aeroplanes in echelon at fifty metres interval fore and aft and half span interval transversely. A speed of 50 m./s., a spacing of 100 metres, and heights of 1,000 and 1,500 m. are specified.

The grouping of three bombs is given in terms of the containing rectangle, which varies from 10 m. × 15 m. to 30 m. × 50 m. Five photographs from the air show the bombs in groups of three.

Materials—Characteristics, Defects and Treatment

Influence on Aircraft Construction of Recent Research on Materials. (P. Brenner, Z.F.M., Vol. 24, No. 18, 28/9/33, pp. 497-504. D.V.L. Report, No. 346.) (10.00/27589 Germany.)

A survey is made of progress in metallurgy, plywoods, built-up spans and welded joints, in reference to possible lightening of construction. Corrosion tests show the improvement in protective measures. X-ray photographs of welds show faults not perceivable from external inspection.

Twenty references.

Effect of Very Low Temperature on Tensile Properties of Metals. (W. J. de Haas and Sir R. Hadfield, Phil. Trans. Roy. Soc., Vol. 232, A.715, 6/12/33, pp. 297-332.) (10.100/27590 Great Britain.)

Temperatures of $-182°C.$, $-253°C.$ and $-269°C.$ are produced by the evaporation of liquid air, hydrogen and helium. The first was applied in the Hadfield-Dewar series of experiments previously published. The second is employed for the most part, and the third for a few cases in the present series.

The results of tensile and Brinell tests are tabulated. Analyses are given of forty-one test pieces comprising pure iron, four carbon steels and thirty alloy steels. In general all metals show increasing tensile strength, but iron loses ductility almost completely, while all the other metals show increased ductility. Steels, alloyed with other metals, especially nickel, retain their ductility. The apparatus and method of test are described.

Four references.

[A bibliography is given in the Dewar-Hadfield paper; Jnl. Iron and Steel Institute, 1905, p. 147.]

Internal Stresses in Large Forgings. (G. Kirchberg, Z.V.D.I., Vol. 77, No. 27, 8/7/33, p. 732.) (10.100/27591 Germany.)

The experiments were carried out by the A.E.G. on cylindrical turbine forgings, approximately 20ins. diameter and 40ins. long. A series of rings and discs were cut out of the forgings, and from their dimensions, both before and after cutting, internal stresses were calculated using the method of Sachs (Z. für Metallkunde, Vol. 19, 1927, p. 352). The results show maximum stresses of the order of six tons per square inch. This is less than the usual practical allowance.

The Behaviour of Metallic Substances under Static and Alternating Stresses. (P. Ludwik, Z. Metallk., Vol. 25, No. 10, Oct., 1933, pp. 221-228.) (10.100/27592 Germany.)

The behaviour of metals under stress is intimately connected with changes in the lattice structure of the constituent crystals. The beneficial effect of a preliminary stress on the ultimate fatigue limits is important.

Fifteen illustrations and thirty-five references.

Spark Tests of Commercial Steels. (R. W. Buzzard, Bur. Stan. J. Res., Vol. 11, No. 4, Oct., 1933, pp. 527-540.) (10.100/27593 U.S.A.)

From author's abstract:—

The sparks are formed by the action of an abrasive wheel with a peripheral speed of 5,000 feet per min. Typical spark streams of plain carbon steels, a variety of alloy steels—including S.A.E. steels—nitrided steel, and cast iron are described and illustrated. A supplementary study was made of the appearance of the metal pellets collected from the spark streams of the various types of steel.

Four references.

Niresist, a High Grade Cast Iron. (Z.V.D.I., Vol. 77, No. 42, 21/10/33, p. 1142.) (10.100/27594 Germany.)

The cast iron contains monel metal and ferro chrome and has an austenitic structure. It is easy to work, almost non-magnetic, and resists corrosion and heat much better than ordinary cast iron.

One reference.

Determination of Effective Young's Modulus. (R. R. Wiese, Aero Digest (Aviation Engineering), Vol. 23, No. 3, Sept., 1933, pp. 40-42.) (10.100/27595 U.S.A.)

Experimental values of the deflection, at points along a composite metal beam and the tangent at the node, are plotted graphically. Deflections measured from the tangent are proportional to the differential coefficient of the ratio M/I. Working back from these values by graphical methods, the effective value of E is obtained from point to point.

In a numerical example the tabulated values at given points show fairly consistent values of Young's Modulus for a steel spar.

The Fatigue Strength of Screwed Bolts and Means for Improvement. (A. Thum and H. Wiegand, Z.V.D.I., Vol. 77, No. 39, 30/9/33, pp. 1061-1063.) (10.104/27596 Germany.)

The notching effect of the thread reduces the strength of a screwed bolt by one-half. It is essential that the bolt be screwed home tight, so as to impose a preliminary compression. With a loose nut the fatigue limits are much lower, on account of play in the screw threads under manufacturing tolerances. Various forms of lock nuts are described. In some designs a tapered thread is employed in the nut. In this way the stressing on the nut can be rendered more uniform.

Seven references.

Welded Tube Construction. (A. Hilpert and O. Bondy, Z.V.D.I., Vol. 77, No. 26, 1/7/33, pp. 701-706.) (10.140/27597 Germany.)

Numerous examples of light and heavy welded tube structures are illustrated by sketches and photographs. Crushing tests to destruction by flattening and axial buckling are also shown. An official test specification is quoted, and curves of permissible loading are given.

Advantages and disadvantages are considered, lightness and economy of material compensating the increased cost.

Stainless Steel for Aircraft. (P. Brenner, Z.V.D.I., Vol. 77, No. 42, 21/10/33, p. 1135.) (10.140/27598 Germany.)

An austenitic steel (18 per cent. cr. and 8 per cent. Ni.) has been used in America for aircraft construction. The material is made into strips which are spot welded to form various built-up spar sections. Although this steel becomes liable to corrosion when heated to 600°C., no trouble is incurred in practice owing to the small area of the spot weld and the short time of heating.

Krupps in Germany have developed a new steel (V. 2a and V. 4a extra) which can be welded without difficulty and does not corrode at the welds, provided a temperature of 700°C. is not exceeded.

Hardness Behaviour of Duralumin. (H. O'Neill, J. F. B. Jackson and G. S. Farnham, Phil. Mag., Vol. 16, No. 108, Nov., 1933, pp. 913-929.) (10.231/27599 Great Britain.)

The hardening and softening changes under heat treatment were investigated by the Meyer ball test. The composition of the alloy is specified, and quenching,

ageing, re-heating before and after ageing, and rolling processes are tabulated with hardness figures before and after cold rolling.

X-ray determinations of the molecular lattice were made. The conclusions are not susceptible of concise summary.

Six references.

The So-Called Incubation Period in the Self-Hardening of Duralumin. (W. Fraenkel and R. Hahn, Z. Metallk., Vol. 25, No. 8, Aug., 1933, pp. 185-189.) (10.231/27600 Germany.)

Samples of duralumin were kept at 500°C., and then quenched in water. The mechanical properties, *e.g.*, Brinell hardness and tensile strength, improve with time during self hardening, generally reaching a maximum 20 hours after quenching. The lag, in some cases as much as two hours before the observable beginning of the process, is called the incubation period and could not be correlated with other physical properties of the alloy.

Experiments on Repeated Hardening of Duralumin Rivets and on the Influence of the Hardening Temperature. (M. Abraham, Z. Metallk., Vol. 25, No. 9, Sept., 1933, pp. 203-205. D.V.L. Report 353.) (10.231/27601 Germany.)

The repeated hardening has a negligible effect on the subsequent period of age-hardening. This period is primarily settled by the temperature at which the age-hardening proceeds. A storing temperature of 8°C. is recommended, instead of the more usual ice-box treatment. This keeps the rivets in a workable condition for 10 hours—a usual working day.

Nine references.

Aluminium Alloys. (Werft-Reederei-Hafen, Vol. 14, No. 20, 15/10/33, pp. 283-289.) (10.231/27602 Germany.)

A summary is given of the Aluminium Conference in Hamburg (14/9/33), and includes application to naval and aircraft oxidation and protection from corrosion, welding, rolling, riveting and pressing processes.

Photographs show examples of German products.

Corrosion Tests with Hydronalium. (P. Brenner, Z. Metallk., Vol. 25, No. 10, Oct., 1933, pp. 252-258.) (10.231/27603 Germany.)

Hydronalium is an Al. alloy containing magnesium up to 7 per cent., and is similar in composition to the alloy " magnalium " introduced about 30 years ago. Improvements in technique have now led to the production of a consistent material highly resistant to corrosion by sea water. The present price is high.

Thirteen references.

A New Light Alloy Specially Suited for Pistons. (Autom. Tech. Zeit., Vol. 36, No. 20, 25/10/33, p. 517.) (10.231/27604 Germany.)

A new aluminium alloy containing 14 per cent. silicon with small additions of Ni., Cn. and Mg. has been developed successfully in the U.S.A. This alloy has a thermal expansion which is 18 per cent. less than that of the normal alloys and closely approaches that of Ni. cast iron, which is in common use for cylinder liners. Pistons made of the new material require correspondingly less clearance cold.

Excellent results are claimed in car and aero engine practice.

Research on Protective Fluxes of Magnesium when Melting and Casting. (M. Hardouin, Pub. Sc. et Tech., No. 28, 1933.) (10.232/27605 France.)

The viscosity of the molten flux is as important as its fusibility and density. Good results have been obtained with fluorides as melting fluxes and borates as casting fluxes.

Krupp Nitriding Process. (Z.F.M., Vol. 24, No. 14, 28/7/33, p. 405.) (10.260/27606 Germany.)

The Krupp patent (No. 386510) covers the use of certain alloy steels in connection with the ammonia nitriding process. According to information supplied by the patentees, the nitrided layer, apart from hardness, improves other mechanical properties of the steel, such at fatigue limits and ultimate tensile strength. The treated steel shows high resistance to corrosion, but is attacked by inorganic acids.

Nature of Polish Layers. (J. A. Darbyshire and K. R. Dixit, Phil. Mag., Vol. 16, No. 108, Nov., 1933, pp. 961-974.) (10.262/27607 Great Britain.)

The polished surfaces of ten conducting metals and two non-conductors, Se and Si, were examined by electron diffraction. In all cases an amorphous layer was observed resembling supercooled liquid. The conductors showed the minimum interatomic spacing, but the non-conductors retained the normal spacing.

Nine references.

Determination of Timber Beams with Two Flanges. (W. Prager, Z.F.M., Vol. 24, No. 19, 14/10/33, pp. 521-523.) (10.400/27608 Germany.)

A typical stress strain diagram for timber under simple axial stress shows asymmetry about the zero point with smaller breaking load under tension than under compression. This is taken into account in calculating the breaking couple under bending moments. Simplified formulæ are developed, and numerical values are plotted graphically.

Two references.

The Strength of Pinned Joints in Wood, Using Various Forms of Mortice. (P. T. Landsem, Z.V.D.I., Vol. 77, No. 37, 16/9/33, pp. 1015-1016.) (10.404/27609 Germany.)

This is a review of American work carried out by the National Committee on Wood Utilisation. The choice of mortice depends largely on whether the work is assembled in the factory on site, and whether a permanent or dismountable connection is required. Apart from this, the mortices illustrated are equally effective.

Three references.

Elastic Tube Connection without Welding. (Flugsport, Vol. 25, No. 14, 5/7/33, pp. 291-292.) (10.404/27610 Germany.)

The joint ends of the pipe are expanded conically and clamped on a double conical washer of petrol-resisting rubber by a screw cap, or by wire levers as applied to bottle stoppers.

Synthetic Resins. (O. Kraemar, Z.F.M., Vol. 24, No. 14, 28/7/33, pp. 387-393, and No. 15, 14/8/33, pp. 420-426. D.V.L. Report, No. 340.) (10.404/27611 Germany.)

A survey is given of aeronautical applications of bakelite and similar materials of which phenol formaldehyde is the chemical basis. Application to instruments, electrical fittings, mountings and insulators is common practice.

" Mikaita " is the trade name given in U.S.A. to a composite material made up of bakelite reinforced internally by layers of embedded fabric; it has been

applied to airscrews with some success. The favourable influence of the embedded material on the type of fracture is shown by photographs in comparison with the " short " fracture of pure bakelite. Test results showing the physical properties are given in tables in comparison with pine and with birch plywood.

Sixteen references.

Annealing of Glass. (L. H. Adams, J. Frank. Inst., Vol. 216, No. 1, July, 1933, pp. 39-71.) (10.406/27612 U.S.A.)

Internal stresses are discussed on a purely mechanical basis in terms of the elementary relations of mathematical elasticity. Stress optical relations supply accurate tests for residual stresses. The conditions for any desired degree of annealing can be determined precisely, without reference to internal constitution of the vitreous materials.

Thirty-five references.

Testing Apparatus and Methods of Testing

The Small D.V.L. Wind Channel. (F. Seewald, Z.F.M., Vol. 24, No. 20, 28/10/33, pp. 559-562. D.V.L. Report, No. 341.) (11.10/27613 Germany.)

The channel has an open jet 1.2 m. diam. and a closed rectangular wind circuit with guide vanes at the four angles. Details are given of a six component balance which gives measurements of three forces and three couples rapidly. The substantial suspension required for sufficiently stiff mounting of the model has no serious influence.

Three photographs show the general arrangement of the balance chamber, details of the balance, and a model suspended in three jets.

Two references.

Full-Scale Wind Channel. (S. J. de France, N.A.C.A. Report, No. 459, 1933.) (11.10/27614 U.S.A.)

A brief descriptive account is given with a specification of performance. Four photographs show the building and three views of the jet and test chamber.

Wind channel test results are plotted with flight tests for comparison, and show very close agreement between lift curves, but discrepancies between the drag curves—which are small at low incidence but increase with incidence.

Near stalling speed, both lift and drag curves indicate that stalling sets in at lower incidence in flight tests.

Present Position and Tendencies of Experimental Aerodynamics. (A. Eula, L'Aerotecnica, Vol. 13, No. 8, Aug., 1933, pp. 1021-1037, and No. 9, Sept., 1933, pp. 1181-1192.) (11.10/27615 Italy.)

A brief description is given of various types of wind channels. The appearance of turbulence affects the results of hydrodynamical theory based on non-turbulent flow, and methods of rendering turbulent motion visible are required. Reference is made to remarks of Prandtl on instability of fluid motion.

Correction for Rolling Moments of a Wing in a Wind Channel of Circular Section. (M. Biot, Z.F.M., Vol. 24, No. 15, 14/8/33, pp. 410-411.) (11.16/27616 Germany.)

Following Prandtl, the method of images is used to form and express analytically the external distribution of images. The effect on the rolling moment is obtained by integration and is found to be of the order of three per cent. in a numerical example.

Seaplane Research. (H. M. Garner, J.R. Aer. Soc., Vol. 37, No. 274, Oct., 1933, pp. 829-863.) (11.22/27617 Great Britain.)

A concise but comprehensive survey is given of the special problems arising in water-borne aircraft and the methods devised for their investigation. Some account is given of existing tanks and of experimental results, of which typical examples are reproduced.

The measurement of water resistance on hulls and floats has long been carried out in water tanks on lines generally similar to tests of ships' hulls, much complicated by the gradual transference of drift and resistance from water to air and from hull or floats to wings. The principles underlying scale correction are discussed briefly. The same complication applies to problems of stability, for which formal mathematical expressions have been developed comparatively recently, on lines generally similar to the theory of stability of an aeroplane completely air-borne.

Landing shocks and impact pressures of waves have received much attention in Germany, and the methods developed there have been studied and applied in this country. The nature of transmission and absorption of shocks of brief duration raises important problems in the theory of structures, which require investigation, and methods of measurement have been developed.

A critical discussion was opened by the Director of Scientific Research, and the views of the scientific and technical staff of the Service and the constructors were elicited.

Drive and Measuring Instruments for Self-Propelled Ship Models. (Summary.) (Ing. Schmierschalski, Werft-Reederei-Hafen, Vol. 14, No. 14, 15/7/33, pp. 201-202.) (11.22/27618 Germany.)

A comparison is made of types of self-contained equipment designed for such tests. The great difficulties imposed by the small scale of the apparatus have been overcome, and an accuracy of one to two per cent. is suggested.

A comparison is made of the Hamburg, Vienna and Washington equipments. Calibration and running characteristics are reproduced from the Hamburg Institute.

A photograph shows a compact general arrangement.

Gamma Ray Testing. (G. E. Doan, J. Frank. Inst., Vol. 216, No. 2, Aug., 1933, pp. 183-216, and No. 3, Sept., 1933, pp. 351-384.) (11.47/27619 U.S.A.)

The upper limit of X-ray penetration of steel is from 8-10 cm., and for deep penetration use is made of gamma rays.

A summary is given of elementary physical theory of radiography and a comprehensive list of radio-active materials is given in tabular form. A photograph shows a lead screen and two photographs show the mounting of test pieces. Radiograms are reproduced to illustrate the relative penetration and scattering of X-rays and gamma rays.

Loss of energy by absorption, and times of exposure required, are shown graphically as functions of the thickness of the test piece. The rate of action of photographic films is increased 35-fold and the exposure times reduced inversely by using thick screens of calcium tungstate in contact with the film. Exposure times are shown graphically as less for X-rays for thickness of steel less than 4in., and less for γ-rays above this thickness. Flaws occupying 2 per cent. of the depth in an object 4in. thick are detected.

In routine testing a number of specimens should be arranged round the source of γ-rays and the source can be removed from a finished group to another group ready mounted for test, such continuous multiple operation greatly reducing costs.

Photographs show test specimens mounted for inspection, including large steel castings, and radiograms show specimens of films. A cost analysis is given.

Forty-five references.

Comparison of X-Rays. (L. S. Taylor, G. Singer and C. F. Stoneburner, Bur. Stan. J. Res., Vol. 11, No. 2, Aug., 1933, pp. 293-308.) (11.47/27620 U.S.A.)

From authors' abstract.—The X-ray output per effective (rms.) milliampere of tube current is found for full wave and constant potential to be nearly the same at any given value of the effective (rms.) voltage. The X-ray quality, as expressed by a full absorption curve, is found to be the same for all wave forms having the same effective (rms.) value, and regardless of peak values. It is thus possible to express the quality of any radiation in terms of the effective voltage used to excite it.

Ten references.

X-Ray Tube with Rotary Anode. (H. Wendt, Z.V.D.I., Vol. 77, No. 31, 5/8/33, p. 853.) (11.47/27621 Germany.)

The anode consists of a copper cylinder with a tungsten cone rotated at 2,000 r.p.m. by eddy currents in a rotary magnetic field. Higher duty is obtained without additional cooling and without overloading the anode, the reflecting surface of which is changing continuously.

X-Ray Test of Ship Materials in Dock. (Schatzmann, Werft-Reederei-Hafen, Vol. 14, No. 15, 1/8/33, pp. 207-209.) (11.47/27622 Germany.)

Two general and three detailed photographs show high tension cables led to ships in dock, and the disposition of the apparatus for testing boilers, brackets, and tubes. Three typical X-ray photographs are reproduced.

Six sections cut from a defective bracket are shown for comparison with the X-ray photograph which revealed the defect.

Airships

German Engineering Conference, Friedrichshafen, May, 1933. (W. Parey, Z.V.D.I., Vol. 77, No. 27, 8/7/33, pp. 725-731.) (12.10/27623 Germany.)

The principal lecture, dealing with airship development, advocated improvements in aerodynamic performance of medium-sized hydrogen airships. The use of helium at present is a severe handicap.

Wireless

Audio-Frequency Atmospherics. (E. T. Burton and E. M. Boardman, Proc. Inst. Rad. Eng., Vol. 21, No. 10, Oct., 1933, pp. 1476-1494.) (13.1/27624 U.S.A.)

From authors' abstract.—Various types of musical and non-musical atmospherics occurring within the frequency range lying between 150 and 4,000 cycles have been studied. Dependence of atmospheric variations on diurnal, seasonal and meteorological effects are discussed. Characteristics of audio-frequency atmospherics are shown in oscillograms and graphs.

Seventeen references.

Automatic Recorder of Ionosphere Heights. (T. R. Gilliland, Bur. Stan. J. Res., Vol. 11, No. 4, Oct., 1933, pp. 561-566.) (13.30/27625 U.S.A.)

A description is given of the apparatus, with a photograph and diagram of connections. Examples of continuous records are reproduced, and the diurnal changes in the ionised layers are discussed.

Five references.

Measurements of Heights of Ionosphere. (T. R. Gilliland, Proc. Inst. Rad. Eng., Vol. 21, No. 10, Oct., 1933, pp. 1463-1475.) (13.30/27626 U.S.A.

From author's abstract.—This paper is a report of continuous measurements of the virtual heights of the ionized regions of the upper atmosphere. Records are shown which indicate the variability, especially at night. The changes are so abrupt and irregular that data taken over a longer period, and for other frequencies will be necessary before it is possible to establish the relative importance of such things as magnetic storms, meteor showers, sun spots or thunderstorms.

Seven references.

Report of Committee on Radio Propagation Data. (Proc. Inst. Rad. Eng., Vol. 21, No. 10, Oct., 1933, pp. 1419-1438.) (13.30/27627 U.S.A.)

From author's abstract.—The frequency range covered is 150 to 1,700 kilocycles, and distances up to 5,000 kilometres (3,107 miles).

The essential results are given in the figures. These comprise a series of graphs giving received field intensities under various conditions, and a series of graphs showing the limitations upon reception imposed by atmospheric and man-made noise and by fading.

Six references.

Attenuation of Overland Radio Transmission. (C. N. Anderson, Proc. Inst. Rad. Eng., Vol. 21, No. 10, Oct., 1933, pp. 1447-1462.) (13.32/27628 U.S.A.)

From author's abstract.—Data on the effect of land upon radio transmission have been obtained during the past few years in connection with various site surveys for the general frequency range 1.5 to 3.5 megacycles per second, and for various combinations of over-water and over-land transmission. Curves are developed which enable field strength estimates to be made for over-land transmission in the extended frequency range.

Eight references.

Calculation of Modulation Products in a Three-Electrode Valve. (A. C. Bartlett, Phil. Mag., Vol. 16, No. 107, Oct., 1933, pp. 845-847.) (13.5/27629 Great Britain.)

From author's abstract.—If to the grid of a three-electrode valve voltages of two different frequencies, f_1 and f_2, are applied simultaneously, then, owing to the non-linear characteristic curve, the anode current will contain components of all frequencies of the form $mf_1 \pm nf_2$, where m and n are any integers. Such components are usually termed modulation products.

A modified form of Taylor's theorem is derived, which allows functions of cosines to be developed directly in series of cosines of multiple angles. This is applied to the determination of the modulation frequencies in a non-linear device such as the thermionic valve.

Harmonic Production in Thermionic Valves. (D. C. Espley, Proc. Inst. Rad. Eng., Vol. 21, No. 10, Oct., 1933, pp. 1439-1466.) (13.5/27630 U.S.A.)

Author's abstract.—Formulæ are obtained for the amplitudes of harmonic components and the direct-current change in the anode current of thermionic

valves operating with resistive loads. These expressions for components up to the sixth harmonic are given in terms of points taken from the load line on the anode-voltage anode-current characteristics at equally spaced intervals of grid voltage.

Two references.

Experiments on Methods of W./T. Communication in Long Range Flights. (P. v. Handel, K. Kruger and H. Plendl, H.F. Technik., Vol. 42, No. 1, July, 1933, pp. 11-20. D.V.L. Report, No. 330.) (13.6/27631 Germany.)

Long-distance wireless on short wave-lengths is subject to fading. In fixed stations great power, combined with directional antennæ at both ends, mitigates the fading. In aircraft or mobile stations generally the question of weight and size limits the feasible power.

The D.V.L. have obtained promising results by using alternately two antennæ, which are polarised to a different extent. Details of the circuits are given.

Performance Tests of Radio System of Landing Aids. (H. Diamond, Bur. Stan. J. Res., Vol. 11, No. 4, Oct., 1933, pp. 463-490.) (13.6/27632 U.S.A.)

From author's abstract.—Details are given of the final stage of development of the Bureau of Standards system of radio landing aids designed to assist aircraft in making safe landings during fog or other condition of low or zero visibility.

Performance data are given on the operation of the system over an extended period of time, which indicate its complete practicability for commercial use.

Three references.

Course and Quadrant Identification with Radio Range Beacon System. (F. W. Dunmore, Bur. Stan. J. Res., Vol. 11, No. 3, Sept., 1933, pp. 309-325.) (13.6/27633 U.S.A.)

From author's abstract.—Certain circumstances may arise, especially near the radio beacon, when a pilot may pass from one course or quadrant to another without his knowledge of it. When once so lost, he may wander many miles in an attempt to reorient himself, since the four courses are all practically identical, and two of the four quadrants between the courses give identical indications.

This paper describes a method of obviating this difficulty by transmitting a directive signal composed of one dot in a westerly direction, a similar signal of two dots in an easterly direction, three dots north and four dots south.

Four references.

Short Wave Beacon Control of Landing in Bad Weather. (H. Jacobshagen and E. Kramar, Z.F.M., Vol. 24, No. 18, 28/9/33, pp. 493-495.) (13.6/27634 Germany.)

A technical description is given of an experimental short-wave beacon at Tempelhof, illustrated by a photograph showing the frame and experimental shed, and by diagrams of field strengths and directions, etc.

Piezo-Electric Loud Speaker. (S. Ballantyne, Proc. Inst. Rad. Eng., Vol. 21, No. 10, Oct., 1933, pp. 1399-1408.) (13.81/27635 U.S.A.)

From author's abstract.—The present paper is concerned with a description of an electrophone unit adapted for the reproduction of the higher audible frequencies and suitable for use as a component of such a composite reproducing system.

The instrument is of the horn type and is driven by a piezo-electrically-active diaphragm built up of crystals of Rochelle salt (sodium potassium tartrate), in which the piezo-electric effect is enormously greater than that exhibited by other materials. It is, however, somewhat more capricious in its dependence upon temperature, humidity, polarisation and variation from specimen to specimen.

Six references.

Photography

Aircraft in Relation to Petroleum Technology. (H. Hemming, J.R. Aer. Soc., Vol. 37, No. 274, Oct., 1933, pp. 864-899.) (14.14/27630 Great Britain.)

Survey of unexplored country by air is far more rapid and less expensive than ground survey, and incorporates a wealth of detail quite unattainable by land survey—with any comparable expense in time and money.

Interpretation in terms of geological formation is referred to experts in petroleum geology, and questions of road, river, and railway transport to transport engineers. These requirements affect the rapidity, accuracy and scale of the air photographic work. Most of the examples are taken from practice in U.S.A. and Canada.

The problem of costs is analysed, and specifications of air equipment are given. Specimens of survey photographs are reproduced, with marking denoting the interpretation of surface characteristics. Air transportation is discussed, and a description is given of transport problems in practice—with examples of equipment and materials carried. Specimen costs are tabulated.

Five references.

Comparison of Photographic Developers. (R. Davis and G. K. Neeland, Bur. Stan. J. Res., Vol. 11, No. 3, Sept., 1933, pp. 379-407.) (14.60/27637 U.S.A.)

From authors' abstract.—In a study of several photographic developers, including the international sensitometric standard, p-aminophenol, it was found that the latter agent is not as satisfacory as certain metol-hydroquinone developers in two respects:—

(1) The " toe " region of the characteristic curve is increased, accompanied by an increased inertia.
(2) The recommended formula is not well chosen in that the solution is supersaturated.

Seventeen references.

Slide Rule for Setting Photographic Apparatus. (Capt. Petitot, Rev. F. Aer., No. 48, July, 1933, pp. 739-760.) (14.90/27638 France.)

A discussion is given of the numerous factors affecting the exposure and development of a plate according to colour and intensity of light, aperture, choice of emulsion, etc.

An abac is constructed to give rapid determination of exposure time in reference to time of year, state of sky, colour of subject and diaphragm. Subsidiary abacs give the height of the sun and intensity of lighting according to day and hour.

The methods are combined in a slide rule which contains, besides numerical graduates, scales of colour ranging from dull grey to snow, and clouds directly illumined, and of sky from bright sun to pearly overcast conditions. The length of shadows in relation to the height of the object is determined by the slide rule for the interpretation of photographs.

Recently Patented Camera Shutters. (W. Lind, Z.V.D.I., Vol. 77, No. 27, 8/7/33, pp. 733-736.) (14.90/27639 Germany.)

Details are given of improvements in the well-known Compur shutter. A high-speed shutter developed by Zeiss employs continuous rotation of three sectors.

Twenty-four diagrams.

Sound

The Theory of Hearing and Percussion Noises. (G. v. Békésy, Phys. Zeit., Vol. 34, No. 15, 1/8/33, pp. 577-582.) (15.20/27640 Germany.)

In a physiological experiment the drum of the living ear is excited directly by plucking. Observation of the resulting vibration determines frequency and damping. The formation of surface waves on the basilar membrane is inferred from experiments on the apparent direction of percussion noises and demonstrated directly by a model of the human ear.

Reflection of Sound Waves, Vertically Incident, by the Ground. (E. Eisner and K. Kruger, H.F. Technik., Vol. 42, No. 2, Aug., 1933, pp. 64-67. D.V.L. Report, No. 331.) (15.26/27641 Germany.)

The experiments were carried out from a small semi-rigid airship. A pneumatically operated whistle sent out notes of frequency 2,900 Hertz. The intensity of the echo was measured electrically by an impulse meter. The reflecting power of water, ice, meadow, and woodland are of the order 1, 1.1, 0.5, and 0.3. The results are influenced greatly by local air disturbances.

Four references.

The Problem of Air Sounding. (Cdt. Laboureur, Tech. Aéron., No. 128, 1933, pp. 121-125.) (15.26/27642 France.)

The author describes the Laboureur-Dubois altitude recorder which works on the Behm echo principle. The novel feature is the recording device which gives a continuous reading. Short sound impulses are emitted by the aircraft at regular intervals, each impulse starting a neon lamp. The returning echo extinguishes the lamp. The current flowing in the interval charges a condenser, the subsequent discharge of which gives a continuous current reading depending on the altitude.

It is stated that satisfactory air tests have been carried out and a series order placed by the French Air Ministry.

Noise Reduction

Frequency Analysis of Noises and Application of Method to the Investigation of Noise in Aeroplanes. (F. Eisner, H.F. Technik., Vol. 42, No. 2, Aug., 1933, pp. 53-64.) (15.3/27643 Germany.)

The method consists in superposing on the noise a so-called " search note " of pure sine form, the frequency of which is slowly varied. The resulting differing tones are analysed. The processes of reception and analysis may be separated conveniently by recording the noise on a sound film. Sections of the record can be used to reproduce the noise for the corresponding time interval and to analyse it as convenient.

Sixteen references.

Silencing of Sounds in Pipe Lines. (G. Buchmann and W. Willms, Schelltechnik, Vol. 6, p. 12, 1933; Phys. Ber., Vol. 14, No. 19, 1/10/33, p. 1503.) (15.38/27644 Germany.)

Various forms of silencing by interference, acoustic filters, and variation of exhaust cross-section are discussed. A practical application of the latter is described, which gave a noise reduction of 22 Phon (decibels) on a pumping installation.

Wall Thickness—Maximum Permeability of an Ultra-Sonic Sound. (E. Hiedemann and H. R. Asbach, Phys. Zeit., Vol. 34, No. 19, 1/10/33, pp. 734-735.) (15.38/27645 Germany.)

In accordance with Rayleigh's theory and subsequent extensions thereof, the optimum thickness is shown to be an integral multiple of the half wave-length by optical methods.

Six references.

Astronomical Air Navigation. (M. A. Bastide, Rev. F. Aer., No. 48, July, 1933, pp. 761-774.) (15.5/27646 France.)

A note is given on methods of astronomical fixes from aircraft proposed by three Italian writers. In particular, a specimen set of observations and numerical reductions is reproduced as prepared by Capt. A. Biseo for a flight from Freetown, Liberia, to Pernambuco, and the points are shown on a map.

One fix is obtained at sunrise and another at mid-day. On reaching the latitude of Fernando Island the latitude is followed till the island is sighted and a new departure taken for Pernambuco.

The flight was realised later by an Italian squadron under General Balbo.

Accidents and Precautions

Flame Traps. (F. Kuhn, Autom. Tech. Zeit., Vol. 36, No. 13, 10/7/33, pp. 336-339.) (16.00/27647 Germany.)

Flame traps consisting of sieves or tubular bundles can be inserted in the induction pipe or in the carburettor intake. The former gives better protection with a marked drop in power, but no complete immunity, and consequential fires may be set up if liquid fuel is present by leakage.

The experiments were carried out on a six-cylinder engine by ignition in one of the cylinders near the end of the induction stroke. The back-fire was propagated at very high speed, probably on account of the high turbulence of the mixture. Momentary pressure rises of the order of 30lb. per sq. in. were observed in the induction pipe.

Flame Traps Using Porous Material. (F. Mörs, Z.V.D.I., Vol. 77, No. 35, 2/9/33, pp. 960-961.) (16.00/27648 Germany.)

The patented flame trap is designed for welding plants using oxyhydrogen or oxyacetylene gas. A cartridge charged with porous material saturated with salt crystals is inserted in the vent. A blow-back perforates a tinfoil diaphragm and the flame is extinguished in the trap before the gas escapes into the air. A fresh cartridge must then be inserted, but the same filling would serve for a number of blow-backs.

Aircraft—Unorthodox

Aerodynamical Principles of the Lifting Airscrew. (M. Schrenk, Z.F.M., Vol. 24, No. 15, 14/8/33, pp. 417-419; No. 16, 28/8/33, pp. 449-454; and No. 17, 14/9/33, pp. 473-481. D.V.L. Report, No. 345.) (17.00/27649 Germany.)

The author states that the formulæ previously developed are not definitely related to the physics of the problem, nor in a form suitable for designers, and professes to fill the gap by the method of the present paper. Well established methods are followed and known results obtained so far as mathematical analysis is applicable.

The author divides the total losses into three parts, the loss due to the induced resistance, the loss due to the axial " slip " and the loss due to asymmetry. The total losses are checked by test measurements and investigations into the sources of error are facilitated by the sub-division.

Constant reference is made to English work and it is not easy to find any fundamental departure therefrom. It may be agreed with the author that knowledge of the physical phenomena is highly imperfect in respect of the actual aerodynamical conditions and consequently of the imposed forces and that further investigations are urgently required.

High Speed Autogiro. (J. A. J. Bennett, Z.F.M., Vol. 28, No. 17, 14/9/33, pp. 465-470.) (17.05/27650 Germany.)

The usual approximations are made and expressions for lift and resistance are formed. The condition of zero aerodynamical moment is expressed in terms of a double integral which is expanded in a rapidly convergent series. Some of Lock's results are quoted and numerical values are computed and plotted in diagrams which show the effect of varying the parameters of design. The conclusion is reached that above 250 km./hrs. the autogiro requires much less power than a comparable aeroplane.

[This appears to assume the validity of the approximations made when the flying speed approaches the mean peripheral speed of the autogiro blades.]

Boomerang and Autogiro. (J. Mottez, L'Aéron., No. 172, Sept., 1933, pp. 207-213.) (17.05/27651 France.)

An elementary aerodynamical theory of the boomerang is constructed. The hinging of the wing spars at the axle eliminates gyroscopic precession of the axis of the autogiro.

Stipa Aeroplane. (L. Stipa, Riv. Aeron., No. 7, July, 1933, pp. 13-37.) (17.30/27652 Italy.)

The body is hollow and presents the appearance of a circular wind channel. The experimental characteristics of two model bodies are given graphically and sectioned sketches show the dimensions in side and end elevations.

A full size aeroplane has been built and the engine is installed near the mouth of the wind channel, with the airscrew rotating in the entry. General arrangement sketches and nine photographs show details of construction, engine installation and the complete machine. Comparative weights, power, surface and performance are tabulated in comparison with three other aeroplanes of similar engine power.

The range of speed of the Stipa is slightly higher, but the average performance appears to be rather lower.

Photographs show models with two, three and four airscrews mounted in parallel wind channels passing through the aeroplane structure.

Equilibrium of Tailless Aeroplanes. (G. A. Mokrzycki, L'Aéron., No. 171, Aug., 1933, pp. 73-75.) (17.30/27653 France.)

The elementary expression for variation of pitching moment is written down and graphical charts show the experimental relation between incidence and moment, and the condition for equilibrium.

One reference.

Principles Underlying the Construction of Rotary Wings. (C. B. Strandgren, L'Aérophile, No. 7, July, 1933, pp. 209-215.) (17.30/27654 France.)

In the apparatus designed by the author the sustentation is produced by paddle wheels rotating about a transverse axis. The paddles are mounted on independent axes and oscillate so as to vary their effective incidence through a small controllable angle. (See Abst. 27526.)

Piskorsch Rotary Wing Aircraft. (Flugsport, Vol. 25, No. 18, 30/8/33, pp. 397-398, and No. 19, 13/9/33, pp. 409-410.) (17.30/27655 Germany.)

The model described resembles the Rohrbach proposal (see Abstract 27654). Instead of being arranged, however, on the circumference of a cylinder the wing elements form part of a conical surface, the angle of the cone being variable. In addition the individual wing elements are elastic so that they can assume automatically an effective angle of incidence. No details as to the mechanism are given but it appears that horizontal, vertical and hovering flight will be possible without the provision of an additional propeller.

Aircraft Carriers

French Aircraft Carriers. (Rev. F. Aer., No. 48, July, 1933, pp. 821-831.) (18.00/27656 France.)

A brief description of the " Commandant-Teste " and the " Béarn " is illustrated with 14 photographs showing the vessels and details of equipment and operations—flying off deck, hoisting in, hoisting up a towed " apron," and stowing.

Maritime Aviation—Leaving and Landing on the Parent Ship. (Lt. Barjot, Rev. F. Aer., No. 51, Oct., 1933, pp. 1083-1104.) (18.3/27657 France.)

Launching by catapult is discussed. Landing on deck requires powerful braking. Modern forms of wing flaps such as the American Zap and the French Pouit construction are described and machines with these devices are illustrated.

Thirteen references.

Meteorology and Physiology

The Clearance of Fog in Industrial Buildings. (A. Lichte, Z.V.D.I., Vol. 77, No. 40, 7/10/33, pp. 1089-1095.) (19.10/27658 Germany.)

In many industrial undertakings work has to be carried out in the presence of open tanks containing heated liquids. Under these conditions fogs are liable to form, especially in cold weather. The author uses the steam diagram to determine the quantity and temperature of ventilating air required to disperse a fog.

Six references and seventeen diagrams.

Determination of Cloud Velocities. (L. Martinozzi, L'Aerotecnica, Vol. 13, No. 7, July, 1933, pp. 890-903.) (19.10/27659 Italy.)

The elementary geometry is given of nephoscope observations and of reduction of oblique observations to zenith (angular) velocities. The subsequent application to determinations of wind velocities at various altitudes is of importance to air navigation.

Eight references.

Treatment of Air Sickness. (A. Gymnich, Z. F. M., Vol. 24, No. 19, 14/10/33, pp. 523-525.) (19.20/27660 Germany.)

A descriptive account is given of the circumstances under which air sickness appears. Medical examination tests and classification of pilots are discussed and prophylactic measures are considered.

Respiration of the Pilot as Affected by Physical, Technical and Toxiological Conditions. (E. Gillert, L.F.F., Vol. 10, No. 3, Oct., 1933, pp. 87-144.) (19.20/27661 Germany.)

The problem is fully discussed in 87 pages. The pilot is affected by low pressure apart from deficiency of oxygen and a limit of endurance may be taken as about 14 km. Even at lower altitudes continued oxygen breathing is harmful. Under these conditions the comfort of the pilot and his freedom from physical and mental strain become important factors.

Two hundred and eighty-nine references.

The Physiological Effect of Speed on the Pilot. (A. L. Flamme, Rev. F. Aér., No. 51, Oct., 1933, pp. 1139-1151.) (19.29/27662 France.)

Many unexplained accidents, including those attributable to error of judgment, are due to a temporary breakdown of the pilot's nervous system. Much stricter medical examinations are required. Gastro-intestinal reactions should be specially studied as an important index of the physiological effect of high speeds.

Orientation in Aircraft by Means of the Senses. (A. Gemelli, L'Aerotecnica, Vol. 13, No. 10, Oct., 1933, pp. 1294-1324.) (19.29/27663 Italy.)

The importance of the labyrinth of the ear in judging changes of direction is considered to be over-rated and no judgment of orientation or direction is to be attributed to the human senses. The homing of pigeons remains unexplained. Flying by instrument will become more general in the future.

Sixty-eight references.

Lighting

Transparency of Fogs. (Z. Instrum., No. 7, July, 1933, p. 304.) (21.22/27664 Germany.)

Experiments with artificial fogs at the Reichsanstalt confirm the greater fog penetration of infra red rays with increasing wave length in the range 0.6 μ to 9 μ.

Aerodynamics and Hydrodynamics

Experimental Researches by Marey on Motion in Air and Water. (P. Noguès, Pub. Sc. et Tech., No. 25, 1933.) (22.10/27665 France.)

Jules Marey (1830-1904) was the first to apply accurate instruments to physiological investigations. In his studies of the motion of birds and insects the registration was carried out by highly ingenious mechanical instruments. These

were later replaced by photographic methods which anticipate the modern cinema. Subsequently the work was extended to the motion of air and water by photographing small particles suspended in the current.

Extension of Hele-Shaw's Method to Cyclic Motion. (Riabouchinsky (summarised by P. Léglise), L'Aéron., No. 166, March, 1933, p. 58.) (22.10/27666 France.)

In Hele-Shaw's well-known experiment on the flow of a viscous fluid between plates set close together, the motion is a cyclic. By constricting the channel and the flow on one side of the aerofoil section, the flow is diminished on that side and a cyclic component round the section is set up.

The velocity field can be measured from the photographs of the observed streamlines, and the pressure field and lift calculated.

Flow of Viscous Fluid Behind a Body. (Parts I and II.) (S. Goldstein, Proc. Roy. Soc., Vol. 142, No. A.847, 1/11/33, pp. 545-573.) (22.10/27667 Great Britain.)

In Part I the viscosity is taken to be small, and the approximations and methods of Blasius and Prandtl are applied to obtain first and second approximations. A third approximation along these lines is shown to fail.

The results, applied to the case of a flat plate, are computed, tabulated, and compared with experiments by Fage. There is close agreement immediately behind the tail, but at half the plate length down-stream there is serious divergence, which may be due to instability and breakdown of laminar flow.

In Part II the viscosity is not assumed to be small, and reference is made to Filon's analysis (see Abstract 5106). The body is of arbitrary shape and consideration is given to the wake far down-stream. Approximations are introduced at an earlier stage than by Filon, and justified *à posteriori*, lead to the same results. Filon's results are confirmed, in particular the failure of the attempt to obtain a third approximation for the moment when there is cyclic flow round the body. The moment is found to be logarithmically infinite, and Goldstein explains this by the displacement of the wake by the circulation field.

Flow of Viscous Fluid Past Rotating Bodies. (T. E. Garstang, Proc. Roy. Soc., Vol. 142, No. A.847, 1/11/33, pp. 491-508.) (22.10/27668 Great Britain.)

Following Stokes, Oseen and Lamb, neglecting the so-called inertia terms, the solution depends on that of a subsidiary linear differential equation with constant coefficients. The solution is found in terms of series of Legendre functions with arbitrary coefficients which are determined by the body conditions. Lift and drag are found to be independent.

The results, which have been arrived at by two different methods, are in contradiction with experiment and with the Kutta-Joukowski theorem for a perfect fluid. It is concluded the Oseen approximations fail when the coefficients are determined for the conditions at the boundary of the body.

A Development of the Michell Theory of Lubrication. (T. Kobayashi, J. Soc. Mech. Eng., Japan, Vol. 36, p. 246; Phys. Ber., Vol. 14, No. 19, 1/10/33, p. 1505.) (22.10/27669 Japan.)

The load-carrying capacity and frictional resistance are calculated, using Michell's theory modified to account for end and oil-groove effects.

Stability for Three-Dimensional Disturbances of Viscous Fluid between Parallel Walls. (H. B. Squire, Proc. Roy. Soc., Vol. 142, No. A.847, 1/11/33, pp. 621-628.) (22.15/27670 Great Britain.)

The assumptions are made that the disturbances can be expressed as a sum of disturbances periodic in time and space, and that the squares of the disturbing velocities and their derivatives may be neglected. With these simplifications a fourth order differential equation is obtained. From the form of the equation it is inferred that the critical value for a two-dimensional disturbance is smaller than for a three-dimensional disturbance.

Still considering only two-dimensional disturbances, if the transverse component (v) is zero, the motion remains in equilibrium from (u) disturbances parallel to the stream (as is, indeed, physically obvious).

Cavitation and Rapid Local Changes of Density. (Riabouchinsky (summarised by P. Léglise), L'Aéron., No. 166, March, 1933, pp. 56-58.) (22.15/27671 France.)

Photographs and sketches illustrate the elementary theory, the mounting of the experiment and the formation of cavitations for a sphere, a disc with sharp edge and a rectangular plate with sharp edges.

In the case of air, lycopodium powder renders visible the formation of tubes of vorticity, which act very much like the cavitations found in water.

Researches on Guttulation (Atomisation) in Diesel Jets. (Werft-Reederei-Hafen, Vol. 14, No. 15, 1/8/33, pp. 209-212.) (22.2/27672 Germany.)

The application of pressure jet injection has made remarkable progress, which depends largely on effective sub-division of the fluid and distribution of the drops in the explosion space. In one method the drops are sampled by exposure of a surface wetted with glycerine in the line of the jet. Photographs of samples magnified to 50 diameter are reproduced. The drops are counted and their diameters measured. The frequency of each size of drop is plotted against the diameters. A family of frequency curves shows the distribution under different working conditions.

In another method the drops are photographed as they stream past a camera. The process of splitting a drop is illustrated diagrammatically in two sketches.

Reference is made to research in U.S.A. and a diagram is reproduced showing the jet space divided into a number of zones by contour lines of equal distribution of fuel.

Three references.

Eddies Produced by Jets in Slow Motion. (H. Bouasse, Pub. Sc. et Tech., No. 26, 1933.) (22.2/27673 France.)

Eddies of various types were formed experimentally by jets with free emission or impact on surfaces and the course of their development studied. Elementary formulæ are developed for the size, shape and motion of the eddies formed. While these are purely empirical, any mathematical physical investigation should be guided in choice of approximations by the general form of these expressions.

The author states that he has never observed an eddy which was not formed by rolling up of sheets of fluid and regards this as a challenge to the theory of vortices presented by rational hydrodynamics. After Reynolds' manner, he insists on the need for visual observation of fluid motion.

Laminar Diffusion of a Jet. (H. Schlichting, Z.A.M.M., Vol. 13, No. 4, Aug., 1933, pp. 260-263.) (22.2/27674 Germany.)

A small circular jet issuing at right angles to an infinite plane wall, from an orifice therein, is assumed to extend by viscous diffusion only, without instability of the steady flow. A form of solution of the differential equations of viscous fluid motion is assumed and indeterminate coefficients are determined by the boundary condition. Numerical values are tabulated and shown graphically.

A solution of the two-dimensional problem is given without the analysis, and the velocity distribution is given graphically for comparison with the circular jet.

(Apparently paradoxical results are obtained with respect to the total flow across planes parallel to the plane boundary. Without a detailed examination it is not possible to assess their significance nor to see whether they arise from the simplifying assumptions made at the beginning.)

Turbulent Flow Through Fine Eccentric Clearances. (R. J. Cornish, Phil. Mag., Vol. 16, No. 108, Nov., 1933, pp. 897-912.) (22.2/27675 Great Britain.)

Observed values are plotted graphically and compared with the known mathematical solution for laminar flow and with empirical formulæ for turbulent flow. The latter are based on v. Karman's empirical formula, which has since been considerably modified.

Ten references.

Rotating Flow in Pipes. (E. Traub, Ann. d. Phys., Vol. 18, No. 2, Sept., 1933, pp. 169-192.) (22.2/27676 Germany.)

A description is given of the technical apparatus for imposing a rotational component of motion on flow through a pipe. The distribution of axial velocities is heavily affected. A series of measurements is plotted and agrees well with a semi-empirical equation due to V. Bjerknes. When a rotational component is superposed the axial velocity rises from zero at the boundary to a maximum at a fraction of the radius and falls again to a minimum at the axis, where a cusp may be formed. When the tube contracts a double maximum may be formed in the curve of axial velocity distribution along the radius.

Reference is made to water spouts and an application to the stabilising of an electric arc is discussed.

Nineteen references.

Generation of Turbulent Flow in Pipes. (H. Kurzweg, Ann. d. Phys., Vol. 18, No. 2, Sept., 1933, pp. 193-216.) (22.2/27677 Germany.)

Following Schiller and Naumann, the entry to the pipe has a sharp edge at which a sheet of intense vorticity is generated, passes into the pipe, and breaks up into eddies.

A rational expression is formed for the circulation round each eddy in terms of the observed mean velocity, contraction and eddy spacing. This quantity, divided by the kinematic viscosity, forms a non-dimensional parameter which is stated to have a critical value, 1170, independently of variations in the parameters involved, and in the other physical parameters introduced by the mounting of the experiment.

(The phenomenon is fundamentally different from that presented by Osborne Reynolds's experiment with smooth entry and laminar flow down to the critical point, and the criteria are not related, apart from the fact that both cases are problems of instability of viscous fluid motion, and this imposes certain common characteristics on the form of the expressions involved.)

Thirteen references.

Flow Phenomena in Rough Pipes. (J. Nikuradse, Forschungsheft, No. 361, July/Aug., 1933.) (22.2/27678 Germany.)

Pipes were roughened artificially by attaching sand grains of different average sizes to the surface. The average amplitude of the roughening is denoted by a linear quantity k, and the ratio r/k was introduced by R. V. Mises as a non-dimensional parameter in a generalised coefficient of resistance. The present report covers experiments on roughened pipes for six different values of the new parameter, which are compared with flow in " smooth " pipes. At higher Reynolds numbers the usual expression for coefficient of resistance as a function of Reynolds number which is independent of r/k, gives six distinct unicursal curves.

A new formula introducing the parameter r/k has been devised by the author and reduces all six sets of observations to a single unicursal curve. The velocity distributions are also discussed and Karman's well-known expression exhibiting the velocity as proportional to the $1/n$th or power of the distance from the wall, where n may be 7, 8, or a higher power as Reynolds number increases. The value of n is shown to be a function of r/k, as well as of Reynolds number.

Turbulent Layer on Curved Surface. (H. Wilcken, Ingenieur Archiv., Vol. 1, No. 4, Sept., 1930, pp. 357-376.) (22.2/27679 Germany.)

Two channels of rectangular section, 90 mm. × 650 mm. were bent (on the flat) through semicircles of mean radii 450 mm. and 150 mm., so that the experiment deals with flow through a curved channel rather than with flow over a curved surface in the usual sense. The radial velocities are kept small by the flattening of the section. Extensive explorations of the pressure and velocity fields are exhibited graphically.

Much business is made of Prandtl's " mixing path " and the associated parameters, including the " apparent viscosity " which has a more definite physical meaning, and an elaborate transformation is carried out of Prandtl's semi-empirical relations to cylindrical co-ordinates. Comparisons are made with experimental measurements on flat plates.

Eight references.

Skin Friction of Various Surfaces. (S. D. Gehmann and S. D. Mallory, J. Frank. Inst., Vol. 216, No. 3, Sept., 1933, pp. 339-350.) (22.3/27680 U.S.A.)

Measurements were made of the skin friction in an air current of various fabrics and surface, with a view to improving the drag of the outer cover of an airship.

The method consisted in suspending a test cylinder inside a rotating cylinder, the clearance being of the order of $\frac{1}{4}$in. The test cylinder is covered with the material to be investigated and its deflection under torsion control is a measure of the skin friction. The dimensions of the apparatus are controlled by consideration of flow stability as has been demonstrated by Taylor.

The experiments indicate that after a certain limiting value of skin friction has been approached any further improvement becomes increasingly difficult. Provided the material is light and does not flap, existing airship covers approach this limit.

Law of Resistance of Small Spheres in Viscous Media. (T. Sexl and E. Wasser, Phys. Zeit., Vol. 34, No. 15, 1/8/33, pp. 605-608.) (22.3/27681 Germany.)

In a previous article by Wasser (Phys. Zeit., Vol. 34, p. 257) the Cunningham formula has been discussed incorrectly. The correct development is of importance in molecular physics and sub-electronic phenomena.

The Turbulent Layer in Two-Dimensional Flow with Rising and Falling Pressure. (E. Gruschwitz, Ingenieur Archiv., Vol. 2, No. 3, Sept., 1931, pp. 321-346.) (22.3/27682 Germany.)

Measurements were made of the velocity field about a wing profile and show a characteristic jump in the velocity gradient at the surface when the observing station moves downstream through the critical point at which turbulence sets in. It is stated that the desired results were not obtained in a simple form. Further measurements were therefore made of the velocity field near a flat plate and are exhibited graphically for a range of channel wind velocities.

All series show the characteristic jump in the velocity gradient, the critical point advancing nearer the leading edge as the channel velocity is increased. The pressure field is also explored. The apparent viscosity is plotted and shows a characteristic maximum of convection of momentum. Elaborate reductions of the results are made in terms of the parameters of Prandtl's theory.

Improvements in the Schlieren Method. (H. G. Taylor and J. M. Waldram, J. Sci. Inst., Vol. 10, No. 12, Dec., 1933, pp. 378-389.) (22.4/27683 Great Britain.)

The method utilises differences in the refractive index from that of air, to produce an optical trace on a screen of the flow of gases. This includes the flow of hot air through a cold atmosphere, which has recently found considerable application in aeronautics.

A description is given of the apparatus used, with various improvements. The necessary elements of optics are briefly referred to. Eight photographs of flow are reproduced.

Twenty-nine references.

Lift on Flat Plate Near Wall. (S. Tomotika, T. Nagamiya and Y. Takenouti, Aer. Res. Inst., Tokyo, Report 97 (Vol. 8, No. 1), August, 1933.) (22.4/5.20/27684 Japan.)

The mathematically more general problem of a plate between two plane boundaries has been very fully discussed by Rosenhead (Proc. Roy. Soc., A.132, 1931, pp. 127-152), in examination of T. Sasaki's work on the same lines. A discrepancy was explained by the omission of a constant of integration and numerical values were computed for small ratios of the parameter such as usually occur in practice. Formal expressions for the effect of a single wall were found as limiting values when one of the two boundaries is taken to infinity.

Elliptic functions are necessarily introduced by the methods of conformal transformation and the whole paper is in effect a discussion of the appropriate elliptic functions and their transformations. In the present paper the limiting case of a single plane boundary is worked out *ab initio*. The work follows Rosenhead's analysis very closely until the new boundary condition is brought in. The analysis then becomes more specialised. Forms suitable for work computations are developed and numerical values are plotted and tabulated.

Theory and Application of the Mach-Zehnder Interference Refractometer. (H. Schardin, Z. Instrum., Vol. 53, No. 9, Sept., 1933, pp. 396-403, and No. 10, Oct., 1933, pp. 424-436.) (22.4/27685 Germany.)

A brief account is given of the principles and construction of the refractometer. Disturbances of the air by a passing projectile, by a hot wire, etc., disturb the initial parallel arrangement of the interference fringes.

Two photographs show the disturbance produced by a horizontal heated wire and by a moving projectile. The isothermal surfaces deduced in the former

case are shown graphically. The pressure distribution along the path of a sound wave is shown graphically for four time intervals.

In Part II the theory of the refraction pattern from a linear source and the application of polychromatic light are discussed.

The relation between the refractive index, density and temperature of air is expressed in a simple form for small changes of the variables. Application to the disturbance of the field interference fringes by the passage of a projectile is illustrated by a worked out numerical example. Other applications are considered.

Hydrodynamics. (Bénard and Journaud (summarised by P. Léglise), L'Aéron., No. 166, March, 1933, p. 60.) (22.45/27686 France.)

Following Terada, Journaud has carried out experiments on a layer of viscous fluid flowing over a plane and heated from below. The mode of instability takes the form of elongated rectangular prisms with transverse cyclic motion.

(This mode is referred to in " Nature," February, 1925, p. 300, paragraph (*c*).)

Thermal Convection of Liquid. (Y. Hudino, Aeronautical Research Institute, Tokyo, Report No. 96 (Vol. 7, No. 15), July, 1933.) (22.45/27687 Japan.)

Examples of natural formations of polygons in mud are shown in three photographs. Experimental reproduction of the conditions in the laboratory yield analogous results, some of which are shown in thirteen photographs. An account is given of the experimental apparatus and the action of the convection currents is discussed qualitatively.

Measured wave lengths of the mode of instability are tabulated. The ratio of wave length to total depth, including the bottom layer of sediment as well as the free fluid is about 1.5, instead of 2.5 as indicated by Rayleigh's analysis. The conditions are, however, much different. There is a layer of water over the layer of silt and the temperature is raised to boiling point with evolution of bubbles.

Two references.

Patterns in an Unstable Layer of Air. (A. Graham, Phil. Trans. Roy. Soc., Vol. 232, A.714, 13/11/33, pp. 285-296.) (22.45/27688 Great Britain.)

Photographs show a number of types of pattern obtained with unstable layers of fluid and observed in the atmosphere.

(No reference is made to the mathematical physical theory developed by Rayleigh, Low, Brunt and Jeffrey, without which the patterns observed by Bénard and many others remain mere experimental curiosities.)

Materials—Elasticity and Plasticity

Motion of a Rotor on Flexible Shaft and Bearings. (D. M. Smith, Proc. Roy. Soc., Vol. 142, No. A.846, 2/10/33, pp. 92-118.) (23.00/27689 Great Britain.)

The equations of motion are formed for a single concentrated mass, for discrete masses and for a distributed mass.

The differential equations are linear generally, linear with reference to rotating axes, or periodic functions of time only. The consequent types of instability are classified.

Some rules for practical design are given.

Anharmonic Vibrations. (J. P. Den Hartog, J. Frank. Inst., Vol. 216, No. 4, Oct., 1933, pp. 459-473.) (23.10/27690 U.S.A.)

A brief review is given of previous work on vibration in systems where stress is not proportional to strain and approximate solutions are given for two new examples, one of which corresponds to a double acting braided rubber (Sandow) shock absorber.

Six references.

Experimental Solution of the Torsion Problem. (H. Cranz, Ing. Arch., Vol. 4, No. 5, Oct., 1933, pp. 506-509.) (23.10/27691 Germany.)

The author applies the electrical analogy due to Kelvin and Tait to the solution of torsion problems. The section to be investigated is sketched on paper and covered by a glass tank containing water, and the boundaries are delineated by metal electrodes at prescribed potentials. Alternating current is passed through the tank and equi-potential lines are marked out by means of a pointer and a vibration galvanometer. The feeding electrodes are arranged so as to satisfy the boundary condition.

The apparatus is shown in a figure with a diagram of connections. Two examples are shown graphically.

Six references.

An Experimental Solution of the Torsion Problems. (H. Quest, Ing. Arch., Vol. 4, No. 5, Oct., 1933, pp. 510-520.) (23.10/27692 Germany.)

The soap film analogy is applied. The slope of the film is measured directly by a refracted beam of light, calibrated from observations on films of circular boundary.

Nineteen figures illustrate the apparatus and show examples.

Ten references.

Optical Path Difference in Stressed Glass. (R. W. Goranson and L. H. Adams, J. Frank. Inst., Vol. 216, No. 4, Oct., 1933, pp. 475-504.) (23.15/27693 U.S.A.)

A beam of plain polarised light passes through the stressed plate, emerging as elliptically polarised light, and passes through a quarter wave compensating plate which transforms it back to plane polarised line in a different plane from the incident beam.

Readings for a divided circle of the angle between the planes of the incident and emergent beam can be averaged to within .10°, corresponding to 0.05 millimicrons, or about 1/100th of the error with a graduated quartz wedge. The elementary optical theory is given.

The apparatus is shown in a photograph and sketches. Examples of readings are tabulated.

Twenty-three references.

Intermittent Buckling Stresses in the Elastic Range in Thin Rods with Articulated Support at Both Ends. (C. Koning and J. Taub, L.F.F., Vol. 10, No. 2, 6/7/33, pp. 55-64.) (23.30/27694 Germany.)

Under the conditions investigated, the Euler load may be safely exceeded if the time of impact is short enough. As long as the impact loads are below the Euler limits, the stresses reach a limit irrespective of time of impact. Above the Euler load the stresses increase indefinitely with increase in time of impact.

Experimental and Theoretical Investigation of Longitudinal Oscillations in Rods and Tubes. (E. Giebe and E. Blechschmidt, Ann. d. Phys., Vol. 18, No. 4, Oct., 1933, pp. 417-456, and No. 5, Nov., 1933, pp. 457-485.) (23.30/27695 Germany.)

The quartz rods and tubes applied as resonators in high frequency measurements have transverse dimensions which are not small compared with the half waven-lengths of the vibrations, and Rayleigh's results require appropriate extension to include the harmonics thus set up, which are in no simple numerical relation to the fundamental. This is carried out for isotropic rods of nickel and nickel alloys. The differential equations are formed and solved and the numerical results are tabulated and compared with experiments. The results for tubes are in the closest agreement with experiment up to 800,000 Hez. Excellent agreement is also obtained with rectangular and cylindrical rods.

In analogy with the methods applied to tubes and cylinders, the coupling between the longitudinal and lateral natural periods is expressed in terms of kinetic energy only. The mathematical expressions are written down and solved for the compound frequencies. These are found to exist in three distinct series.

The calculated frequency spectrum is exhibited in tabular form graphically in comparison with observed values. Remarkable agreements are shown, and discrepancies are explained by the presence of harmonics known to be physically possible but not coming within the scope of the analysis. The coupling coefficient is determined and shown graphically. The results have application to piezo-electric frequency control.

Twenty-two references.

Weights of Typical Beam Sections. (J. Cassens, Z.F.M., Vol. 24, No. 13, 21/7/33, pp. 359-363, and No. 14, 28/7/33, pp. 381-383.) (23.30/27696 Germany.)

Seven typical sections are considered. From the elementary geometry of the sections formulæ are prepared which facilitate the calculation of weight and bending moments and the best dimensions for a given purpose. Built-up girders are discussed with respect to the increase of weight involved in design for uniform load factors in comparison with design for uniform factors of safety.

A table giving simple formulæ involving the load factor and a graphical chart gives numerical coefficients, which facilitate numerical computations.

Four references.

Miscellaneous

The Use of Rubber in Rail Car Wheels. (P. Kramer and G. Reutlinger, Z.V.D.I., Vol. 77, No. 35, 2/9/33, pp. 955-958.) (27697 Germany.)

The rubber is inserted between the steel tyre and the wheel and allows a certain amount of lateral displacement. There is considerable reduction of impact at the rail joints, of noise, wear of the rails, and rate of deterioration of the permanent way. This would allow of lighter construction of the permanent way or alternatively of heavier traffic and higher speeds on existing tracks.

Five references.

Aerodynamic Characteristics of Automobile Models. (R. H. Heald, Bur. Stan. J. Res., Vol. 11, No. 2, Aug., 1933, pp. 285-291.) (27698 U.S.A.)

Sketches and photographs are shown of old style models and new highly-faired models.

Test data are tabulated for resistance and for lateral forces for different angles of yaw. A reduction of about 22 per cent. in air resistance is shown.

Eleven references.

The Fundamental Purpose of the War Car (Tank) in Modern Warfare. (R. Mertz, Autom. Tech. Zeit., Vol. 36, No. 19, 10/10/33, pp. 481-483.) (27699 Germany.)

War cars (tanks) are divided into three classes—for reconnaissance, open warfare, and trench warfare. The relative merits of track and wheel propulsion for reconnaissance are discussed. The fitting of both drives is not considered good. The same judgment applies to the so-called amphibian types, the compromise seriously detracting from the fighting capacity of the tank.

Short-wave wireless sets for inter-communication and reporting to Headquarters have become practicable.

REVIEWS

Keith Lucas

Published by W. Heffer and Sons, Ltd. 5/- net.

This book consists of a number of impressions of Keith Lucas, written by those who knew him. They cover the whole of his life from childhood. The last is written by Major Mayo, well known to readers of this Journal, who worked with him during the time he was at Farnborough.

Keith Lucas was a brilliant physiologist who had been made a Fellow of the Royal Society in 1913, being well known for his original work on muscles and nerves. But he possessed that type of mentality which enabled him to do well any work which came his way, and he had previously distinguished himself in surveying, microscopy and in natural history studies. To each of his subjects he brought a clear mind and a natural instinct for mechanics which found scope in the design of instruments and apparatus.

When he joined the Royal Aircraft Factory, at the outbreak of the war, there were many problems which required a brain used to the habit of going to fundamentals and free from preconceived ideas. Those that fell to him to solve were the design of a bomb-sight and the construction of a satisfactory aircraft compass. To both of these he found solutions, and his early death in an aeroplane accident in 1916 robbed the country of a brain which could ill be spared.

Those who knew him will welcome this book, and those who did not will find much to interest them in the description of a man who stood out among his contemporaries, and who, but for an early death, might have added to our knowledge much that we still want to know.

The Airman's Year Book

Edited by Squadron Leader Burge, O.B.E. Sir Isaac Pitman and Sons, Ltd. Price 3/6.

This book is intended to be used as a book of reference on all matters concerning civil aviation, and is intended for the use of pilots, navigators, ground engineers and others. It is published under the authority of the Royal Aero Club, and is described as being complementary to the air pilot, to which those desiring information on aerodromes are referred.

All ordinary aviation matters about which information may be required are set out here at length. Air Touring, Customs Aerodromes, Meteorological Services, Organisations, Awards, Legal Matters, Air Navigation Regulations and Orders, etc., are all dealt with in a way which makes it possible for the enquirer to find out what he wants to know. That it is not always easy to find any particular item of information is not the fault of the editor, but is due to the dense fog of regulations in which civil aviation is immersed. In this volume no less than 80 closely printed pages are devoted to such regulations and directions, but an abstract of the subject is also given under the heading of " The Law Relating to Civil Aviation," which will save much floundering in the morass of official phraseology.

The book should be extremely useful as a work of reference, for it includes in one volume much information which has hitherto been scattered in many different publications. At its published price of 3s. 6d. the book is very good value for the money.

La Cristallisation des Métaux

By Colonel Belaiew. Published by the Institut de Soudure Autogène, Paris.

It is generally accepted that it is a most difficult thing to describe complicated happenings in such a way that they can be easily understood by everyone. Whoever attempts it must have two qualities which are seldom found together, he must be a master of his subject and he must also have a considerable proficiency in the art of writing.

Colonel Belaiew has both these qualifications, the first to an unusual extent as he is known throughout the world as an authority on the subject with which he deals. The result is a book which sets out more clearly than in any other I know exactly what is believed to happen when a metal solidifies, and explains it in such a way that the mind has no difficulty in forming a mental picture of the process.

In addition, the book is very well illustrated, the quality of the microphotographs is remarkable, and it is worthy of note that the magnifications used range up to $4 \times 4{,}500$. It is a book which no one who wishes to be well informed on these matters can afford to be without. It is understood that an English edition can be obtained from the School of Mines, though this has not the advantage of the latest revisions of the author.

Aerodynamic Theory

Edited by W. F. Durand. Published by Julius Springer, Berlin. Price 24/-.

This book is the first volume of a work intended to present a general view of aerodynamic theory at the present time and also to review the progress made in this subject during the last twenty-five years. It has been arranged for each section of the complete work to be undertaken by a specialist in the particular subject, and the list of names given include Max Munk, Von Kármán, Betz, Prandtl, G. I. Taylor, H. Glauert, and B. Mellvill Jones. It should, perhaps, be stated that the letterpress is in English.

This volume is taken up, primarily, with material dealing with the special mathematical subjects used in aerodynamics, and is by the Editor, W. F. Durand. He commences with a chapter on The Complex Variable, and continues with Fourier Series and the Theory of Dimensions. He then goes on to discuss Vector Algebra and Vector Fields, these two chapters being particularly well done. Potential matters are then discussed, followed by special theorems such as Gauss', Green's and Stokes', and concludes with a useful chapter on Conformal Transformation.

He then treats the subject of Fluid Mechanics, starting with Fundamental Equations, Vortex Flow, Kutta-Joukowski Theorem, etc., continuing with the application of Conformal Transformation to Fields of Flow, and completing with a chapter on Aerostatics which can be particularly commended.

Max M. Munk then continues with the same subject, dealing with the Kinematics and Dynamics of Fluids, Motions of Solids in a Fluid, Sources and Vortices, Ellipsoids of Revolution, etc.

This part of the book is intended to enable those who already possess some mathematical knowledge to understand the special branches of mathematics which are used in aerodynamical subjects, and it should be said that the two authors have covered the ground very well and that their exposition is clear and explicit.

The first volume concludes with a sketch of the history of aerodynamics by R. Giacomelli, assisted by E. Pistolesi. He divides the subject into three periods—from antiquity to Newton, from Newton to Lanchester, and from Lanchester to the present time. The landmarks of the progress of the science are therefore connected with the names of Englishmen. The work of the more important

writers on the subject is well described, and the author's researches must have cost him a considerable amount of time and trouble, which is indicated in the number of books and publications he has found it necessary to refer to. The work is well worth doing, and I have not noticed that anything of importance has been omitted.

This first volume is excellent, both in its choice of subjects and matter, and the remaining volumes will be awaited with great interest.

Applied Hydro- and Aeromechanics

By O. G. Tietjens, Ph.D., based on lectures of L. Prandtl, Ph.D. McGraw Book Co., Inc. Price 24/-.

This is one of the series of books publication of which has been arranged between four American engineering societies and the McGraw Book Co. The present volume is concerned with the technical rather than the mathematical treatment of the flow of fluids.

The first chapter contains a short account of the elements of hydrodynamics, including Euler's equation, Bernouilli's equation and the equation of Navier-Stokes. The second chapter deals entirely with laws of similarity and dimensional analysis. The third chapter commences with the flow in pipes and channels, starting with the work of Hagen and goes on to discuss laminar and turbulent flow, Reynolds number, convergent and divergent flow, etc. The fourth chapter is concerned with boundary layers; the fifth with drag; the sixth with aerofoil theory; and the seventh with experimental apparatus; and the volume closes with a number of photographs of the flow round bodies which are unusually excellent, both technically and from their choice of subject.

This book is essentially one for the aircraft designer, who, as a rule, is not a profound mathematician, and who usually has difficulty in following the theories of aerodynamics in the works of the mathematicians. He will find all the latest information on the subject set out clearly and should be able to follow most of the mathematics without difficulty. The chapter dealing with aerofoil theory is exceptionally important to works of this type and it is one of the best in the book, the derivation of the various formulæ being excellently explained and the matter is assisted by numerous diagrams. The two chapters on boundary layers and drag are also excellent for their clear description of their subjects.

The book is strongly recommended as being much the best book on the subject for the technician that has so far appeared.

Fundamentals of Hydro- and Aerodynamics

O. G. Tietjens, Ph.D., based on lectures of L. Prandtl, Ph.D. McGraw Book Co., Inc. 24/-.

This book is one of a series of selected books which four American engineering societies consider to be of interest to engineers, but which are expected to have a too limited sale for commercial publication. The actual publication is the result of an arrangement between the societies and the publishing firm.

The first part of the book is concerned with the statics of liquids and gases, and, after considering the theoretical aspects, the argument is carried to the application of theory to the atmosphere, and, later on, to gas-filled aircraft. The section concludes with a chapter on surface tension. The second part deals with the kinematics of liquids and gases, starting with the Langrangian and Eulerian methods. The geometry of the vector field is then considered, with the application of tensor analysis to this subject. There is a further chapter on the acceleration of a fluid particle, and a concluding chapter on the equation of continuity.

Part 3 considers the dynamics of non-viscous fluids, including Bernouilli's equation, potential motion, including the Cauchy-Riemann differential equations.

Vortex motion is discussed, and the influence of compressibility, and the section closes with a chapter on the Navier-Stokes equation with Oseens modifications.

The aim of the author can be expressed in his own words: "It is this synthetic process between theoretical hydrodynamics and practical hydrodynamics which stands in the foreground," and it is this general tendency running through the whole scheme of the book which adds considerably to its usefulness. Those concerned with practical aircraft design will find much here to interest them—expressed in a language which they will be able to understand. It will be found that the theories of classical hydrodynamics, though they actually lead to results which are known to be wrong when applied to say, air, yet contain much of great importance to those interested in practical aerodynamics.

The book can be highly recommended.

The Royal Air Force: A Concise History

By Captain A. O. Pollard, V.C., M.C., D.C.M. Hutchinson and Co., Ltd. Price 18/-.

A book on this subject is badly wanted. There is, of course, the Official History of the War in the Air; but this work contains, necessarily, an overwhelming amount of detail, and must be considered, principally, as a mine of information from which the historian can extract his raw material.

The subject is one which would inspire any writer, and one would have expected a novelist like Captain Pollard to have taken full advantage of a great opportunity and to have emphasised the broader aspects. For instance, the growth of tradition in the Royal Air Force occurred in a few short years, while in the other Services it had taken centuries; skill, courage, and imagination were required and were forthcoming, while the whole story was truly described by Sir Walter Raleigh as an "Epic of Youth."

In this the author cannot be said to have succeeded. The book principally consists of a number of incidents, largely and necessarily drawn from the war, the combined effect of which is to confuse the broader aspects; as so much attention has been paid to the trees, the wood itself is not visible. Again, he does not give enough attention to the pre-war history, for it was in those days that the foundation was laid.

There are a number of errors, H.M.S. *Bacchante* was not a battleship, but a small cruiser. Maurice Farman aeroplane did not have 100-h.p. engines. Some ten Zeppelins took part in the Battle of Jutland, of which L.24 and L.31 sent back most useful information. Gotha bombing aircraft flying light were not used as escorts to large bombers, and the chapter on the Theory of Flight is full of mistakes. Captain Pollard would be well advised to omit this chapter in future editions and to replace it by one giving some details of the equipment of the Air Force in machines and weapons. The book should also possess a bibliography.

Although the book is in many respects disappointing, it is the best book on the subject that has so far appeared for the reading of the general public, and it is hoped that it will be widely read. The details of the Royal Air Force, both in peace and war, should be more widely known than they are at present, and in this matter this book will help.

My Air Armada

Air-Marshal I. Balbo, translated by G. Griffin. Hurst and Blackett, Ltd. Price 18/-.

This book describes the flight of the 24 Italian seaplanes from Italy to America, where they attended the Chicago Exhibition, and their return flight to Rome. There is no doubt that the successful accomplishment of this flight by over twenty seaplanes flying in formation is a very notable feat, and one which reflects great credit on the personnel and also on those responsible for the

organisation. Air-Marshal I. Balbo, who was in charge of the arrangements and led the expedition in person, deserves great praise for his success in carrying it through to a successful termination.

Technical interest is naturally largely concentrated on the type of aircraft used, and here the book is rather disappointing. The machine was the Savoia S.55, fitted with two Isotta Fraschini engines of 750 h.p. each, and a speed of 180 m.p.h. is claimed—which is some thirty-five miles an hour faster than the speed credited to them in the usual reference books. As seaplanes, they were excellent examples of the Italian school of design, being twin-float monoplanes having the wings attached directly to the floats, which latter contain the crew. The two engines are carried above the plane in tandem, and the tailplane and rudder are supported by outriggers. The general design is clean, and tends to high-speed, but the lowness of the plane to the water and the general arrangement suggests that the type is not likely to be so seaworthy as the English flying boat, though they may possess ample seaworthiness for the normal conditions in the Mediterranean.

It is probable that the S.55 was a rather difficult machine to land. The design suggests that if one float touched heavily before the other there would be a considerable likelihood of a bad swing, which might easily lead to a crash. This may be the reason of the unexplained accidents on landing, such as that in which Colonel Maddalena was killed; though the difficulty of finding the cause of a crash must be considerably increased when it is necessary to assume " technical perfection " in the machine and " marvellous ability " in the crew.

Air-Marshal Balbo describes the flight in great detail, and there is much that is strange to the English temperament in the contents of the telegrams and messages that were continually passing beween the expedition and the home authorities. Fascism is always well in the foreground. It seems to be an honour to be allowed to wear a black shirt under Air Force uniform, and this is only permitted on special occasions.

The importance of the Italian contribution to the development of America is stressed to an extent which can only be explained by exuberant patriotism, and it appears also that most of the important explorers were Italians, including, rather surprisingly, Christopher Columbus and Cabot. The Author also delves into Irish history, being impelled thereto by his stay in Ireland, but has succeeded in getting his facts rather badly mixed up.

The book is, beyond question, one that should be read. Not only does it give a full account of a remarkable exploit, but those who are politically minded will find much to interest them in the relations of the Italian Air Force with its native country, the King, the Duce, Fascism. Its description of the flight is excellent, but it is a pity that there is not a full account of the technical side—even a good photograph of the machine used would have been appreciated.

The 573rd Lecture read before the Royal Aeronautical Society since its foundation, January 12th, 1866.

THE ROYAL AERONAUTICAL SOCIETY

A meeting of the Royal Aeronautical Society was held in the Lecture Theatre of the Royal Society of Arts, at 18, John Street, Adelphi, London, W.C.2, on Thursday, February 1st, 1934. In the Chair, Mr. C. R. Fairey, M.B.E., F.R.Ae.S., President of the Society.

The PRESIDENT: Before introducing the lecturer, he was going to ask the meeting to elect to Honorary Fellowship, on the Council's recommendation, Mr. J. E. Hodgson (the Society's Honorary Librarian). He explained that recommendations for election to Honorary Fellowship were made to the Society by the Council. There were only 14 Honorary Fellows among 1,500 members, and the honour was very jealously guarded. Under Rule 14 the Council had power to recommend to an ordinary meeting of the Society the names of those whom it considered worthy of election to Honorary Fellowship, and it was his pleasure to put forward the name of Mr. Hodgson, in accordance with the unanimous recommendation of the Council.

The great services rendered to the Society by Mr. Hodgson were well known and appreciated. He was author of "The History of Aeronautics in Great Britain," already a classic, and he was acknowledged the greatest authority on the history of aviation in this country, if not in the world. There was no need to say more with regard to him, and it was with the greatest pleasure that the President asked the meeting to signify in the usual way approval of the Council's recommendation.

Mr. Hodgson was duly elected.

In introducing Mr. J. D. North, he recalled that a short while ago the Society had had the pleasure of hearing a very elevating story of the development of the air-cooled engine, told by Mr. Fedden. It was generally conceded that a great part of that development had been due to improvements in cowling, and the Society was to hear that side of the story from Mr. J. D. North. It was an advantage that, the better known a lecturer was, the less amount of time need be devoted to introducing him. Mr. North was a survivor of a small band of pioneer designers whose experience extended back to 1911 or earlier; he had become an acknowledged leader of design in this country, and the designer of several of our best known aircraft.

ENGINE COWLING

With Special Reference to the AIR-COOLED ENGINE

BY

J. D. NORTH, F.R.Ae.S., M.I.Ae.E.

Historical Review

In the earliest stages of the development of the aeroplane the speed range obtainable was small, flight occurred only at fairly high lift coefficients, and induced drag was the predominant component of total resistance, hence successful flight depended on the achievement rather of minimum weight, minimum wing loading and maximum engine power than on the achievement of minimum possible parasite resistance.

At a very early date the rotary Gnome engine had achieved a predominant position amongst aeroplane power plants.

In the early Farman and similar machines with engines at the rear of the crew, even oil guards on rotary engines were often not used, but as the tractor type of machine became the normal, cowling of more or less standard type was adopted throughout the world for use with this type of engine. Such cowling consisted of a sheet metal hood, which either completely surrounded the engine, or which extended some 270° round the engine, this hood being continuous with the fuselage surface at least over the upper part of that surface, and permitted the escape of exhaust gases, of cooling air, and of oil, only towards the lower part of the fuselage. Without such cowling, the oil thrown out by the engine would have made the crew positions untenable.

Apart from the Gnome and similar types of rotary engine, the only air-cooled engine of pre-war days which used cowling of any kind was the eight-cylinder Vee Renault. The cowling provided for this engine by the makers was essentially a system of air ducts through which cooling air was drawn by a fan, and the cowling was essentially a cooling device, not a resistance reducer. When this type of engine was fitted by the Royal Aircraft Factory to the B.E.2, the fan was omitted and the flow of cooling air through the cooling ducts was induced by the motion of the aircraft, aided by the slipstream from the airscrew, a process made possible by the relatively high speed of this aircraft.

It is interesting to note that neither in the rotary nor in the original Renault air-cooled engine did cooling depend to more than a limited extent on the speed of flight of the aircraft, the rotation of the cylinders in the one case, and the fan in the other providing the relative motion of air and cylinders required.

It is also interesting to note the high proportion of engine power absorbed in rotating the cylinders of the rotary engine and thus ensuring cooling. Speaking from memory, the reaction torque of the nominal 50 h.p. Gnome corresponded to the 50 h.p. rating, the h.p. available was about 37 h.p., some 13 h.p., or 26 per cent. of the power developed in the engine being used up in rotating the engine.

In the case of early water-cooled engine installations, it was originally the custom to leave engine cylinders exposed, and in the majority of cases to use radiators mounted clear of the engine and thus not influencing the form of such cowling as was used. At a somewhat later date radiators mounted ahead of the engine, forming the front end of a cowling not unlike a normal car bonnet, as, for example, in the S.E.5, or larger radiators behind the engine, as in the R.E.7, which might be partially cowled in—came into fashion. The larger rear radiator was arranged with a restricted rear outlet for air and was thus an attempt to reduce cooling resistance by using lowered air velocities for this purpose.

The practice of leaving water-cooled cylinders exposed to the air persisted till a relatively late date, on the assumption that some considerable direct heat

dissipation from the jacket walls was obtainable. This assumption was apparently supported by certain tests made by Gibson (1) showing very high heat emissivity from cylinder barrels, but these results now appear to have been misleading.

In modern water-cooled installations, engines are normally cowled as completely as possible, and radiators retractable within the fuselage, or radiators arranged to be more or less shielded from the free air stream, giving reduced resistance for high speed flight are usually employed. The engine cowling has become merely a case to contain the engine, designed to cause the minimum possible resistance.

FIG. 1.

Cowling of Air-Cooled Engines

Although, as has already been stated, the cowling of air-cooled engines in the early days—even to so late a date as the end of the war—was dictated normally by considerations other than that of reducing resistance, it is not to be supposed that the question of resistance was entirely neglected. One of the earliest efforts at a low resistance engine installation on record is the Paulham-Tatin monoplane designed *circa* 1911, in which a rotary air-cooled engine was completely enclosed in the body, driving an airscrew at the rear of the fuselage through a shaft. Details of the methods by which cooling air was admitted to and discharged from the engine casing are not certainly known, but the aircraft did give a remarkably high speed for its power. Power plant troubles—of which cooling was presumably one—were encountered (Fig. 1).

In 1913 M. Jean Armand Deperdussin proposed means of cowling rotary engines with a view to securing minimum resistance (2). Fig. 2 from Deperdussin's specifications indicate clearly the nature of these cowling schemes. Briefly, the engine is, in all these cases, mounted on the front bulkhead of a fuselage of circular section (at least at the forward end) and enclosed within a casing which, in conjunction with the body, forms substantially a continuous streamline form.

At the front of the cowling an aperture (or apertures) is provided to admit cooling air to the engine. At the rear louvres or other orifices are provided to allow the cooling air to emerge. These rear apertures are, in most examples, confined to the lower half of the cowling circumference to keep oil, etc., away from the pilot, though in some cases ducts are provided to carry the cooling air, exhaust, and oil to behind the pilot's seat.

These efforts to reduce resistance resulted directly from the study of high speed racing machines by the Deperdussin firm, and for such machines, cowling of the type indicated was a practical proposition.

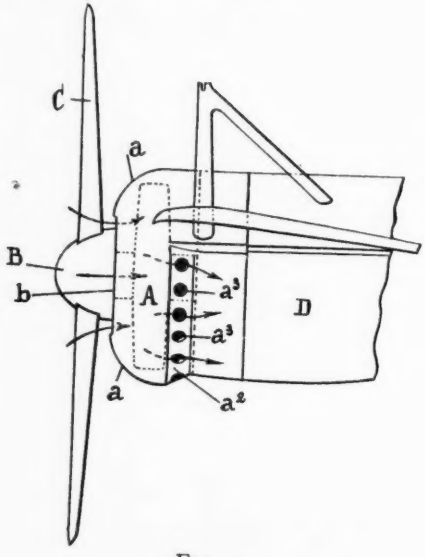


FIG. 2.

The standard type cowling used by all nations during the war for rotary engines was to some slight extent influenced by the ideas shown in these Deperdussin patents.

The cowl, or oil shield, was made to form a continuation of, or was faired into the fuselage lines. The fore end of the cowl was curved inwards to form some semblance of a fair entry to the body cowl lines. But it was not found practicable to approach the complete enclosure of the engine in a streamline casing to the extent indicated by Deperdussin, and a free exit for air, exhaust and oil was normally provided by leaving a large gap between cowl and fuselage over the lower rear part of the cowl circumference. In many cases the cowl itself was cut away completely over the lower quadrant. Any further effort at enclosing the engine was liable to cause overheating.

Towards the middle of the war the Salmson Company, in France, introduced a cowling very similar to some of the forms earlier patented by Deperdussin,

for use with their radial Canton-Unne engines. These consisted of a circular cowling completely enclosing the engine, the ring conforming in diameter and fore and aft lines with that of the body behind, so that cowl and body formed a substantially streamlined whole. The Salmson engines, though of the radial type, were water-cooled, and fitted with annular radiators, mounted within the cowling enclosing the engine. The principle employed was that used on the S.E.5, but the radial arrangement of the engine led to a form of cowling similar to that of Deperdussin.

A similar type of cowling was later applied to Salmson air-cooled radials and by Messrs. Caudron to Anzani radial air-cooled engines.

Other early efforts to reduce engine resistance by somewhat similar means are to be found, but space does not permit of any attempt to deal exhaustively with such early designs of cowling.

In all these early low drag cowlings for radial and rotary engines the essential feature was the enclosure of the engine in a streamline casing which forms a forward continuation of the body lines. To provide for engine cooling, part of the air stream is permitted to enter the engine casing—normally through a central aperture, and to emerge behind the engine by louvres, slots or other openings. In the arrangement of these rear exits for cooling air, there are signs of an effort to direct the cooling stream so that it caused little disturbance to the general flow over the body. Essentially the method of reducing drag consists in all these cases in shielding the engine from the free air stream and in effecting cooling by a stream of velocity considerably reduced by the cowling arrangements.

The engines to which such cowlings were applied were all by the standards of to-day of low power and relatively large dimensions, and hence should have been relatively easily cooled. In some cases satisfactory cooling was apparently achieved with early cowling schemes of this streamline casing type, but the type of cowling was not extensively used and did not persist.

A characteristic of cowling provided with rearwardly facing air outlets surrounding a rotary engine, which does not appear to have been recognised, is that in such a case the engine may act as a rotary blower, inducing a rearwardly directed flow of air at high velocity through the air outlets, capable of producing a measurable thrust, and thus effectively decreasing engine drag. The existence of this effect has been verified in the wind tunnel.

The rotary type of engine, though relatively free from cooling troubles, is subjected to centrifugal and other forces, due to its rotation which increase rapidly with increasing dimensions and increasing rate of rotation. The 230 h.p. B.R.ii engine, which remained in extensive use for some time after the war, appears to have approached the limit of practical development of this type.

The demand during the war for engines of rapidly increasing power, and the difficulties of producing stationary air-cooled cylinders of high output, led towards the end of the war, to an increasing use of water-cooled engines and to at least a partial eclipse of the air-cooled type.

Although the stationary air-cooled engine did not during the war reach a stage which allowed it to compete with available high power water-cooled engines, development work on the air-cooled type continued and to such effect that in the ten years or so following the end of the war, the high powered radial air-cooled engine established for itself the position of being the most widely used type for both military and commercial service throughout the world.

This period of development of the air-cooled engine was also a period of a steadily increasing demand for higher and higher performance in all types of aircraft.

The demand for increased performance may be met either by increased power/weight ratio or by the use of cleaner aircraft, and it seems that the success of the air-cooled radial type of engine during the period 1919-1928 was due at least in part to the relatively low weight per h.p. which it was found possible to

provide in this type of engine. It is certainly true that during this period radial engines were almost invariably used either with no cowling at all or with cowling which had relatively little effect in reducing the drag caused by the engine.

Many efforts were made experimentally in this period towards reducing the drag of the air-cooled radial. Even during the ascendancy of the rotary engine it was realised that the power wasted in driving relatively large diameter radial

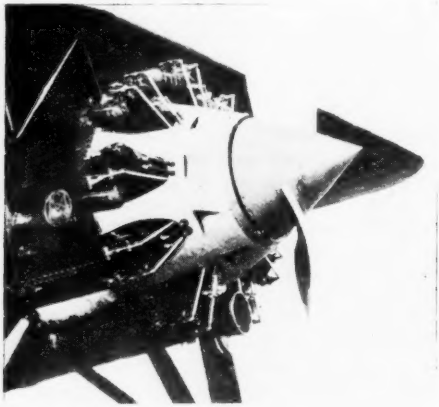


FIG. 3.

FIG. 4.

engines through the air was well worth saving, and as speeds and performance generally increased, this waste of power became more and more important.

Fig. 3 shows a very common arrangement, in which cowling is confined to a casing surrounding the crankcase, of a form to blend into an airscrew spinner forward, and the fuselage behind, the engine cylinders projecting out into the open.

Fig. 4 is a fairly common modification in which a tail is added to the cowling behind each cylinder, with the object of partly streamlining the projection.

Fig. 5 shows a nacelle and cowling used on the Boulton and Paul "Bourges" for an A.B.C. engine. The nacelle and cowling together form a streamline body which would practically entirely contain the engine.

In the cowl proper a series of pockets, one for each cylinder, were provided, the cylinders lying in these pockets, which are open to the outer air.

All these arrangements have their effect on resistance, but unfortunately it is roughly true to say that their efficacy as drag reducers was small and only the

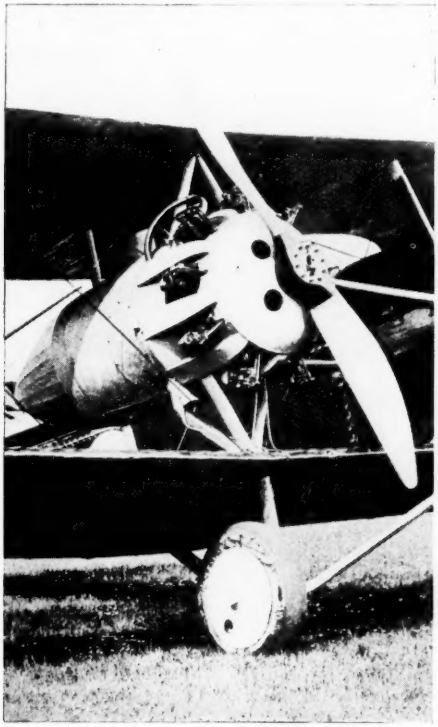


FIG. 5.

type of cowling shown in Fig. 3 has been extensively used for aircraft in regular service. Although this type of cowling is undoubtedly better than nothing (*i.e.*, the bare engine), it is in fact far less effective than its appearance might indicate, and is a very long way from a satisfactory solution of the cowling problem.

Fig. 6 shows the cowling fitted in 1923 to the Gourdon-Leseurre type C.1 aircraft. In this each of the cylinders of the "Jupiter" engine is enclosed in a separate streamline chest, with a limited aperture at the front for the admission of cooling air, and an exit at the rear arranged so that the emerging air may blend with the general air stream. The principle involved is thus similar to that of the single streamline casing enclosing the whole engine, but the individual cylinder casings—or helmets—serve also to confine the air flow within the casing to the region surrounding the cylinders.

This form of cowling is capable of reducing resistance very substantially, but it also has a serious effect on the cooling of cylinders (Ref. 3), and has not been found to be practicable except possibly for very high speed aircraft such as that to which it was applied in the case illustrated.

The growing ascendancy of the air-cooled radial during the years after the war was for a time very seriously threatened as a result of the development in America—by the Curtiss Co.—of the combination of a twelve-cylinder Vee engine of very small frontal area, of the complete enclosing of that engine in a cowling thoroughly well faired to the fuselage lines and the adoption of wing radiators.

It is well to note here that " low frontal area," as the term has often been applied to the case of streamline bodies, is a somewhat misleading phrase, and that frontal area is only a measure of resistance in the case of geometrically similar solids of revolution. It was the possibility of enclosing the Curtiss engine in a body of good shape and of small surface area, rather than of small cross-section, which was of importance.

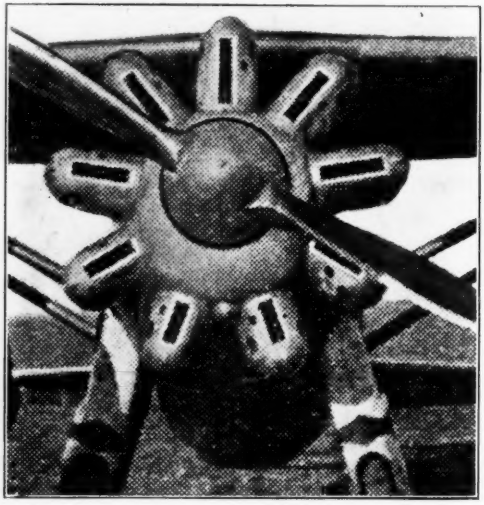


FIG. 6.

This type of engine installation, developed in the first place for racing machines, provided a very convincing demonstration to the world at large of the extent to which performance could be improved by the use of low drag engine installations, and resulted in the production by aircraft manufacturers in several countries of high speed, mainly military aircraft, in which the lead of the Curtiss Company in respect of clean water-cooled engine installations was followed. Experience proved the wing radiator to have serious practical disadvantages, and more practical methods of reducing cooling resistance have had to be adopted.

The last five years have seen the development in England of the Townend Ring, and in America of the original form of N.A.C.A. cowling which, when properly applied, are able to reduce the drag of a radial engine to values only a fraction of those which were previously attainable, without prohibitive interference with cooling. There can be little or no doubt that to the introduction of satisfactory forms of low drag cowling, the radial air-cooled engine owes a renewed lease of life, since, without such means of reducing its resistance to a substantial

equality with that of a modern water-cooled engine and cooling system, the air-cooled radial could not possibly maintain its present wide field of usefulness.

Engine Cooling

It will be quite clear from the historical outline already given that the factor which limited the use of low drag cowlings was that of cooling. Completely to enclose the power plant in a casing of streamline form is the obvious method of obtaining low resistance, and would have been adopted at a very early stage in the development of the aeroplane were it not for the necessity of cooling engines.

It is not necessary here to go deeply into the theoretical aspects of cooling, which have been ably dealt with elsewhere, notably by Pye (Ref. 4). The connection between the heat dissipation of a hot surface moving in a fluid, and the skin friction of the same surface is now a matter of common knowledge, and has as its corollary the inference that the cooling of an aircraft engine must necessarily involve some resistance.

By the use of the wing surface, or the surface of some other necessary part of the aircraft as a cooling surface, it is possible to secure cooling without increase in the resistance of the aircraft—except in so far as the skin friction coefficient may be affected by change in temperature of the air flowing over the surface. But so far it has not become practicable generally to use wing or body surfaces for engine cooling, and the added resistance of special cooling surfaces must therefore be tolerated.

For any given form of such cooling surface, the rate of heat dissipation depends on the temperature difference between the surface and the air, and on the relative velocity of air and cooling surface, being nearly directly proportional to the temperature difference, and varying as some power of the relative velocity, depending on the characteristics of the cooling arrangements, which is of the order of, but rather less than, unity.

In the practical problem of engine cooling as a first approximation the temperature difference between the heat dissipating surface and the air may be regarded as having a constant value, fixed by the permissible upper limit of the boiling point of water in water-cooled engines and of permissible operating cylinder temperatures in the air-cooled case.

Although the amount of heat which has to be dissipated by the cooling surface varies over wide limits with the conditions of flight, it is obvious that the critical cooling condition must correspond to full throttle operation of the engine, and though the power developed by the engine, and the heat rejected to the cylinders, lubricating oil, etc., under full throttle conditions may vary considerably, *i.e.*, with speed of flight, the assumption that the rate at which heat is so rejected is constant at full throttle is also sufficiently near the truth for a preliminary consideration.

In service, the engine will normally be opened up to full throttle for take-off with the aeroplane stationary and remain at full throttle during acceleration on the ground, during climb to operating height, and may remain at full throttle during full speed flight.

Actually at the start, the engine, the cooling fluid, if any, and lubricating oil, are at temperatures substantially below their steady normal operating level, and some considerable quantity of heat is required to raise the whole installation to normal working temperature. The heat used for this warming up process is not dissipated, and the effective heat reservoir afforded by the power plant as a whole prevents excessive temperatures being reached during the initial period of flight in which the air speed of the machine is very low.

Since the rate of heat dissipation from whatever cooling surface may be employed increases with increasing air speed, the condition which will determine the area of such cooling surface is the heat dissipation obtainable at the minimum speed of flight which, in practice, can be maintained at full throttle for any

appreciable period. This condition is generally that of a continued climb at maximum climbing speed.

Pye (4) has made an estimate of the power necessarily expended on cooling a 500 h.p. engine on an aircraft flying at 150 m.p.h., assuming the cooling surface employed to produce skin frictional resistance only, the whole of the friction producing surface being effectively used for heat dissipation.

The h.p. absorbed in overcoming the cooling surface resistance is found to be 6.8 h.p., or about 1.5 per cent. of the engine output.

This estimate is based on the assumption that the heat to be dissipated is equivalent to 50 per cent. of the engine b.h.p., and that the average difference in temperature between cooling surface and air is 180°C.

McKinnon Wood (5), using measured rates of heat dissipation from finned cylinders and finned plates, cooled by air circulated past the cooling surfaces in ducts by means of a fan, and also using measured values of the energy used in so circulating the air, has made an estimate on a somewhat different basis. In this case the temperature difference was taken as 250°C., the heat to be dissipated as 50 per cent. of the engine b.h.p., while the mean speed of the cooling air past the cylinders was only 150 ft./sec. (approx. 100 m.p.h.).

Taking the overall efficiency of the fan at 50 per cent., the power absorbed in cooling was found to be 4 per cent. of the engine output. Allowing for fan losses, the power actually absorbed in cooling is 2 per cent.—a figure not widely different from Pye's 1.5 per cent.

McKinnon Wood further shows that for the finned cylinder assumed, the heat dissipation per h.p. expended in cooling is at approximately one half the rate which should theoretically be obtained if the air resistance were purely frictional.

It will be noted that in McKinnon Wood's estimates cooling does not depend on the flight speed of the aircraft, but entirely on the velocity through the cooling ducts which may be fan induced.

The validity of any estimates such as these cited depend very critically upon the assumptions made, particularly as to the mean temperature difference which is effective for cooling. Both Pye and Wood assume mean values which are obviously attainable only on air-cooled engines. The relatively low estimate of power required to cool from finned cylinders given by Wood depends on the relatively high temperature of 250°C., and for a temperature of 200°C. the power to cool with the method considered would be increased $2\frac{1}{2}$ times. The figures apply only to cylinders having the particular fin form, height and pitch used in the tests, in which two-thirds the cooling surface is cylinder barrel, and one-third flat cylinder head, developing 50 b.h.p. per square foot of such finned cooling surface.

Change in fin proportions, particularly as regards pitch/height ratio, have a considerable effect on heat dissipation and—apparently—appreciably affect the ratio between resistance and heat dissipation. Heat dissipation depends on the mean temperature difference between cooling surface and the cooling air. The temperature of air-cooled cylinders varies over a wide range, for different positions on any cylinder, and it is quite impossible to estimate from available data as to maximum safe temperatures at specified positions of current types of such cylinders, whether the assumed mean temperature differences represent conditions which could be tolerated. Generally Pye's figure of 180°C. would appear to be a nearer approach to what is practically available than the higher figures of McKinnon Wood.

A further fundamental uncertainty, particularly as regards air-cooled engines, is the proportion of the total heat of combustion rejected in various ways. The overall thermal efficiency of such engines is easily ascertainable—the proportion of waste heat carried off by exhaust gases, by the lubricating oil, and the remainder, to be dissipated mainly by the cylinders, is not known. There is evidence that the proportion of total waste heat carried off in these various ways differs widely for different types of engine.

The estimates of power required above cited relate to heat dissipated from cylinders alone, but oil cooling is as essential as cylinder cooling, and except where open exhausts are used, exhaust systems require cooling, and in some cases cause a very substantial increase in resistance. The resistance both of oil coolers and of exhaust systems may properly be regarded as part of the cooling resistance, and adequate allowance should be made for these items on any estimates of power necessarily applied for cooling purposes. The practical importance of such extra-to-cylinder cooling has received considerably less than its fair share of attention, though Mr. Fedden has recently drawn attention to the drag of oil coolers and the possibility of substantial reduction therein.

McKinnon Wood's figures indicate a large divergence between the drag of a practicable cooling surface and the ideal cooling surface wholly effective for heat dissipation, which produces skin friction alone. In the normally exposed air-cooled cylinder—or radiator—the eddy-making drag, which is not effective in promoting heat dissipation, may cause a much larger divergence than occurred in the combination of finned cylinder and air ducts tested by Wood.

Pye, in the article already referred to, gives figures showing that the difference in performance of an aeroplane with a water-cooled engine and retractable radiator showed a difference in resistance, radiator exposed and radiator completely retracted, equal to 9 per cent. of the remaining resistance of the aircraft, the top speed of the machine in question being about 150 m.p.h. Presumably the radiator in question gave sufficient cooling for the engine on the climb, and if the climbing speed of machine was 75 m.p.h., and if the whole of the waste heat rejected through the cylinder walls was required to be dissipated by the radiator during climb, it should from the approximate considerations already used, be capable of dissipating nearly twice the amount of heat required for cooling at top speed.

In fact cooling systems sufficient to cope with climbing conditions are of excessive capacity for flight at high speeds, and tend to become increasingly excessive as the performance of aircraft increases. Fortunately a number of factors tend to reduce the disparity between cooling surface needed for climb and for top speed.

Increasing speed is normally attended by increased rate of climb and decreased time to reach operating height. The capacity of the heat reservoir afforded by the engine itself, and lubricating oil during the rise in temperature from take-off conditions to maximum permitted temperature can therefore absorb heat at a rate inversely proportional to the time taken in climbing.

With water-cooled engines the high specific heat of water provides a very large heat reservoir, and the high latent heat of evaporation of the same fluid permits of the dissipation of heat at a greatly increased rate accompanied by a relatively small loss of water by evaporation.

Thus there is an effective heat ballast system which permits a temporary rate of heat rejection in excess of the rate of dissipation from the cooling system, without temperatures rising to beyond permitted limits.

Cooling systems are normally arranged within the airscrew slipstream, whose velocity is much more nearly constant than is the air speed of the machine itself, and the effective cooling velocity does not vary over such a wide range as does the machine speed.

It may be remarked incidentally that the effect of airscrew characteristics on cooling problems is very considerable. The use of geared airscrews of large diameter operates to reduce the assistance to cooling given by slipstream to some extent. Behind the boss, and for some distance outward therefrom, the added velocity due to the airscrew has a negative value—which may extend over .2 of the whole diameter—and the increase in airscrew diameter following the use of reduction gears, with the consequent increase in the area shielded by the centre of the airscrew, is a factor of considerable importance as regards cooling of radial engines in particular.

The nature of the permissible limits of temperature of an engine installation enters into the question. There is an upper limit, for example, for cylinder heads at which mechanical failure occurs after a very short period. Below such a limit there is a whole range of operating temperatures each corresponding to some life between overhauls of the engine.

Temperature limits are commonly determined as those which continuously maintained are consistent with a particular life between overhauls—generally 100 hours. In regular service, the attainment of these maximum permissible temperatures for a few minutes during climb, followed by a period of cruising flight at substantially lower temperatures, is found to give a service life between overhauls two to three times as long as would result from continuous operation at maximum temperature.

All these factors operate to reduce the disparity between the amount of fully-exposed cooling surface which is needed for climb and for high-speed level flight to something considerably less than would appear to be necessary on first consideration.

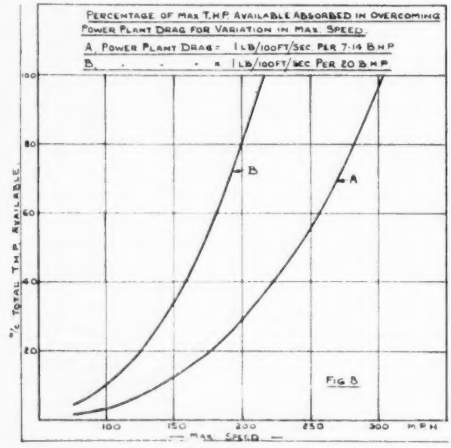


FIG. 7.

It remains generally true that the cooling which has to be provided on an engine installation is determined by the cooling required on climb, that this provides excessive cooling capacity, and consequently excessive drag, at higher speeds. The practical importance of drag of cooling systems increases very rapidly with increase in the ratio of climbing to maximum level airspeeds, since power expended on such drag varies as the cube of the speed, as is graphically indicated by Fig. 7, which shows the variation in the proportion of the total drag of an aircraft represented by fixed cooling systems with variation in maximum speed.

Two different cases are shown, one in which the drag of the cooling system at 100 ft./sec. is 1lb. per 20 b.h.p. (25lbs. for 500 b.h.p.), and the other in which it is 1lb. per 7.14 b.h.p. (70lbs. for 500 b.h.p.). The figures correspond fairly closely to a really good ring-cowled radial installation and to a good radial installation with crankcase cowling only, using current types of air-cooled engines, and does not indicate in any way the limits of reduction in cooling drag which may be possible as a result of engine development or by other means. The figure does not represent the effect, on otherwise identical aircraft, of a change in cowling, since the change to low drag cowling will cause an increase in maximum speed, but indicates directly the change in power spent in cooling on

aircraft designed for equal top speed, and therefore of equal total drag, the saving due to low drag cowling being used, for example, for increasing useful load or fuel.

It does indicate directly the reduction in engine power required for a given speed on such otherwise identical aircraft caused by the assumed change of power plant drag, but such reduction in the power of the engine actually installed would operate still further to reduce the drag, and consequently still larger economies in power expended would become possible.

If the maximum speed of an aircraft with the higher drag cowling of the figure be 175 m.p.h., the cooling drag and h.p. will be 55 per cent. of the total. If the lower drag cowling be fitted, the engine maximum power being not altered, the maximum speed will increase to about 200 m.p.h. If, however, the aircraft with low drag cowling is operated at 175 m.p.h., the cooling drag falls to 20 per cent. of the total for the original machine at the same speed, and the power absorbed and the fuel consumption at 175 m.p.h. falls to 65 per cent. of that of the original machine. The effect on range for equal fuel, on load for equal range, and in engine reliability need only be mentioned. The further economies possible by using an engine of lower output, and still further reduced drag, to give equal performance, need not be laboured.

Means Whereby Cooling Resistance May Be Reduced

Ideal cooling conditions, such as assumed, for instance, by Pye in the estimate of power necessarily absorbed in cooling, are not generally obtainable. The wing radiator for water-cooled engines is rarely practically possible. Steam cooling of the kind proposed by Wing Commander T. R. Cave-Brown-Cave many years ago, has, however, given wing surface cooling a new field of utility. The increase in the mean temperature at which heat is dissipated to actual boiling point reduces the total surface required, and permits of the use of the leading edge of the wing alone, and the low density of steam—as compared to water—greatly reduces the weight of cooling fluid necessarily in circulation. For the steam-cooled case, cooling for little or no added drag, now appears to be a possibility so far as relates to the dissipation of heat from cylinder walls alone. Oil, and exhaust cooling, and the drag of air intakes, remain and assume an added importance in consequence.

The case of steam cooling apart, considerations of weight and bulk, apart from any other limitations, involve the use of cooling surfaces which cause a large degree of eddy making, and consequently resistances considerably in excess of skin friction drag.

In the case of the air-cooled engine, the form of cooling surface is characteristic of the engine itself, and the aircraft designer has no such control over that form as is available in the liquid-cooled case, and has there resulted in the development of wing nose condensers for steam-cooled engines.

Since the drag of any given cooling surface increases as the square of the velocity, while heat dissipation varies at a less rate, cooling drag can be reduced by increasing cooling surface and so shielding the surface from the air that the air speed over the cooling surface is reduced. It should therefore pay the designer of the air-cooled engine to increase the cooling surface/output ratio to enable cooling to be effected at reduced air speeds, which would permit of decreasing the necessary exposure of the engine to the air by means of cowling.

This fact has been recognised by the engine designers, who in producing new type engines have invariably aimed at providing as large a margin of cooling surface as was practicable.

Development of such an engine then proceeds in the direction of progressively increasing the output per c.c. of cylinder capacity, and, with output, the heat

dissipation rate needed for cooling—until finally the cooling margin originally provided disappears and redesign for improved cooling once more becomes necessary.

The fact that the net thrust h.p. available, after deducting engine drag, rather than the b.h.p. developed is a measure of the useful output of the engine, and that the capacity to cool with a low air velocity may lead to a considerable economy both in the ratio net t.h.p./b.h.p. and in the effective fuel economy of the engine, deserves more constant attention than has up to the present been given to it.

The principle of using lowered air velocities and increased cooling surfaces to reduce cooling drag is well known. Junkers has proposed (6) radiators enclosed in casings, open to the air stream, with internal passages expanding from opening to radiator position and thereafter contracting. The radiator is thus at a region of reduced air flow, and, for given cooling, involves lowered drag. The casing was to be given an external form conducive to low drag, and the method is undoubtedly capable of useful results. A large saving in drag by this method involves increase in dimensions and weight of radiator of a substantial amount.

The helmet cowling (Fig. 6), and the enclosure of air-cooled engines in streamline cases (Deperdussin, etc., and the original N.A.C.A. cowlings), depend for their practicability on the engines possessing some excess cooling capacity, and on cooling by the use of a flow of cooling air at a velocity less than that of the free air stream.

Radiators fitted with adjustable shutters or other screening devices have commonly been used to reduce cooling drag at high air speeds. Such arrangements may operate either by reducing the air velocity over the cooling surface, or by reducing the area of the cooling surface exposed to the free air stream during high speed flight, or by a combination of the two.

In modern low drag installations of liquid-cooled engines, the cowling is purely an engine fairing, and cooling is effected by radiators (or condensers) which are not part of the cowling Nevertheless, the development of such low resistance cowling has been made worth while only by the development of low drag cooling organs.

In the air-cooled engine, cowling and cooling are indissolubly associated, and it is in connection with such engines that cowling design to-day is a matter of outstanding importance.

The finned circular cylinder, which serves in such engines as the main cooling organ, is a body of very bad aerodynamic shape whose high resistance is mainly due to eddy making. When such cylinders protrude from an otherwise reasonably good streamline shape, the eddying wake behind the cylinders causes a general break-away of the flow from the body behind, and it is this break-away of flow which is the cause of the high resistance of installations of this type.

The streamline " tails " behind cylinders of Fig. 4 were an effort to suppress the turbulent wake, and hence to prevent the breakaway of flow, but proved to have but a negligible effect (*vide* N.A.C.A. Report No. 313).

Complete " helmeting " on the lines of Fig. 6 are shown in the same report to be exceedingly effective as reducers of drag—but to interfere prohibitively with cooling.

It was only in 1928 that the nearly simultaneous publication of the results obtained by Mr. H. C. H. Townend at the National Physical Laboratory, with the Townend Ring, and of the N.C.A. tests at Langley Field on the original complete N.A.C.A. cowling that any really important advance towards low drag installation of radial air-cooled engines was made.

Ring Cowlings Generally

There still appears to be in some quarters a considerable amount of misapprehension as to the relation between Mr. Townend's original work with the Townend Ring and the tests made by the N.A.C.A. on cowlings in 1928.

Mr. Townend's invention is clearly described in his patent specification (7). The Townend Ring is an annular aerofoil surrounding radial projections from a streamline body, the aerofoil section being arranged to have a positive angle of attack to the local airflow. Mr. Townend found that the inwardly directed downwash from this aerofoil suppressed the breakaway of flow which would otherwise have been produced by the projections, and consequently greatly reduced the resistance of the whole combination.

The earliest account of the N.A.C.A. complete cowling to be published is contained in Technical Note No. 301, which is dated October 13th, 1928, some months later than the date of Townend's patent application. This note records the results of tests on a variety of cowlings for radial engines, including types in current use, the "helmet" type, and the "complete cowling," since particularly identified as the "N.A.C.A." type.

This complete cowling may well be described in terms adopted by the N.A.C.A. themselves:—

> "Cowling No. 9 completely covered the engine. The air was taken in at the nose and allowed to flow past the engine, which was entirely uncowled, and out of an annular slot, similar in section to some wing slots which have been tested. This type of nose and slot were designed to offer as little resistance to the flow of air over the fuselage as possible, separating air for cooling the engine from the general flow and then feeding it back smoothly through the slot" (N.A.C.A. Tech. Note No. 301).
>
> "When the slot was originally designed for the complete cowling (Nos. 9 and 10) it was hoped that it would tend to decrease the drag because of its effect on the boundary layer. A test made on the nacelle with the slot covered, however, showed that the drag is 10lbs. less at 100 m.p.h. without the slot. . . . It is likely that the cooling air could be collected after it has passed the cylinders and directed out through one or two openings at the bottom or sides with no increase in drag over that with the annular slot. The annular slot is, however, a very convenient means for getting the used cooling air back to the general outside flow." (N.A.C.A. Report No. 314, pp. 20 and 21.)
>
> "The now widespread use of air-cooled engine cowlings has brought forth many modifications of the original N.A.C.A. type. In fact *the cowling which was intended to form a smooth streamline shape of the average fuselage with its projecting cylinders* has in some cases been reduced to a small continuous ring above the cylinder heads. . . . A cowling of the latter form, commonly known as the Townend Ring, has been developed elsewhere." (N.A.C.A. Tech. Note No. 335, p. 1, dated Nov. 1, 1930.)

It may be noted in passing that the No. 10 cowling mentioned in the second quotation above differs from No. 9 mentioned in the first quotation by the provision of internal cowling shielding the crankcase and thus increasing the air flow over the cylinders, and by the use of intercylinder baffles.

The statements quoted indicate clearly the essential similarity of the original N.A.C.A. cowling and the early arrangements of Deperdussin. The annular slot arrangement—impossible to Deperdussin on account of the oil-throwing propensity of the rotary engine—is shown to be of no advantage other than convenience. The special arrangements for improving cylinder cooling in the final form (No. 10) are not novel in principle, but only in conjunction with the specific type of cowling.

This comment on the lack of essential novelty in the principle of the N.A.C.A. cowl does not in any way detract from the value of the investigation made at Langley Field on cowlings generally. The discovery that a device proposed before the time was ripe for its general adoption could, with improvements and development, and under the changed conditions of increased speeds of flight and more effectively cooled engines, be of great practical utility, deserves the fullest possible recognition.

It is clear that the ideas underlying the design of the original N.A.C.A. " complete cowling " involved no such novel and broad principle as suppression of the breakaway of flow behind the body by the downwash from an annular aerofoil—a conception entirely novel and one enunciating an aerodynamic principle of first-class importance.

The figures in Townend's specification show no approach to a cowling, which, with the body, forms a streamline whole, enclosing the engine. The ring is something entirely outside of, and divorced from, the general streamline of the body, and it is extremely doubtful if anyone with a reasonable knowledge of aerodynamics, confronted with these figures for the first time, would recognise them as showing forms likely to have a low resistance. I confess freely that I myself at first sight of the Townend Ring concluded that it looked far more likely to increase than to reduce drag.

Particular attention is drawn to the date of the last quoted of the three extracts from N.A.C.A. reports, which refers to " narrow rings." By November, 1930, the results of Mr. Townend's work were widely known in aeronautical circles throughout the world, and the suggestion that such " narrow rings " were merely developments of the original N.A.C.A. cowl is obviously without foundation.

The results obtained with the N.A.C.A. complete cowling attracted extraordinary interest. The great reduction in drag shown was measured on a real engine, driving an airscrew, mounted on a full-scale body, at a speed of 100 m.p.h. The tests included cooling tests on the engine when running, and the cooling of the engine was pronounced to be satisfactory.

The absence of any doubt as to possible scale effect and the evidence as to cooling were properly regarded as of fundamental importance—the latter particularly so in view of the repeated failures of early low drag cowlings to provide this essential.

The early results published by Townend using the ring showed striking reductions in drag, but not such spectacular figures as those of the N.A.C.A. This difference is not surprising, since Townend was investigating a new general principle and his models were of small scale and conventionalised form, whereas N.A.C.A. were essentially engaged in discovering how far the development of a well-known principle could be carried in practice.

It may be noted here that by the time the N.A.C.A. Report No. 314 giving drag tests on a streamline nacelle, Whirlwind engine, complete cowling, was available in this country, tests made in a British wind channel (9) on a nacelle, Jupiter engine, and Townend Ring, had shown drags which corrected for the difference in diameter of the two engines, were practically identical with those obtained by N.A.C.A.

The British tests were made on $\frac{1}{5}$-scale models, fully representative, and hence in themselves might be subject to " scale effect," but full-scale evidence that the Townend Ring can equal the N.A.C.A. type cowling as a drag reducer is now fairly conclusive.

The broad principle underlying the Townend Ring gives the device a number of obvious advantages over the N.A.C.A. cowling. In the latter, cowl engine and body immediately behind engine must all be of substantially equal diameter. The cowl must curve inwardly forward to a considerable degree to give a " streamline entry " to the whole, and hence restrict the entrance for cooling air.

These considerations impose restrictions on body form, which affect field of vision for the crew, field of fire for forward firing guns, and on cooling, which are not present to the same extent when a Townend Ring is used.

The restriction on the entry of cooling air in the N.A.C.A. type cowling is of considerable importance, despite the reassuring nature of the original N.A.C.A. tests of cooling. These were made with an engine having a direct drive airscrew. There is conclusive evidence that with such engines, N.A.C.A. complete cowling, with carefully-designed internal passages and proper cylinder baffles, does give low drag and satisfactory cooling. In this country, efforts to use N.A.C.A.-type cowling on geared engines have been disappointing, and with geared and supercharged engines generally unsatisfactory (10). Even in the U.S.A. difficulty is generally admitted to occur with geared and/or supercharged engines fitted with N.A.C.A. cowls. This difficulty of cooling in the case of geared engines arises undoubtedly from the increased diameter of the region of reduced airscrew outflow with increased airscrew diameter.

With the Townend Ring, the ring alone must be of a diameter substantially equal to the engine, the body diameter behind the ring may be, for best results, of the order of .75 of engine diameter. The pronounced inward curve of the front of the N.A.C.A. cowl is not necessary. Body shape and size are consequently less strictly limited, and view and gun fire less restricted. A less restricted entry and exit for cooling air are provided, and engines which will not cool in an N.A.C.A. complete cowl, cool satisfactorily with a properly designed Townend Ring.

The Townend Ring

Inasmuch as my company have proprietory interests in the patents covering the Townend Ring, and have devoted much attention to the development of this device, I am naturally in a position to give more detailed information concerning this particular form of low drag cowling. I hope that these details will be of general interest.

Although the Townend Ring itself is a simple device, the factors which may influence its performance are many and various, and time will permit only a very general consideration of some of the more important of these factors.

Ring Sections

The section of a Townend Ring is an aerofoil section in so far as it is required to produce a radial outwardly directed lift, with its consequent downwash. The effectiveness of a ring for given conditions is determined by the intensity of downwash per unit of circumference. Hence it is an advantage to use a section which develops a high lift coefficient in order that the chord length required may be a minimum.

Experience shows that, for rings of the usual single-surfaced (plate) type, a camber of about 10 per cent. of the chord length should be used. Double surfaced sections, usually employed for wings, of the same camber on their upper surface, are less effective than the plain plate type, presumably because the mean curvature is reduced to one midway between that of upper and lower surfaces. There is some evidence that an increase of camber to more than 10 per cent. may be advantageous under certain conditions.

The addition to a plate type ring of a bulbous nose similar in form to the leading edge of a moderately thick aerofoil section has been found usually to decrease the drag of the complete ring installation quite appreciably. Such a bulbous nose has been used by Boulton and Paul as an exhaust collector, and provides a method of cooling and silencing the exhaust with no increase, and normally a decrease, in total resistance. Fig. 8 shows ring sections which have satisfactorily been used for Townend Rings.

Angle of Ring Chord

The best angle between the chord line of the ring section and the thrust axis depends on many factors, such as the exact form of the engine, of the body behind the engine, of the section actually used for the ring itself and the relative fore and aft position of the ring relative to the engine. As a very rough guide, useful for determining the range within which experiment may usefully be conducted, the lines of the body may be extra-polated forward past the engine to complete a reasonable streamline, and the chord of the ring should then be set at an angle between parallel to a tangent to the streamline and at about 4° converging rearwardly to that tangent, the tangent being taken in a plane corresponding to 50 per cent. of the chord length.

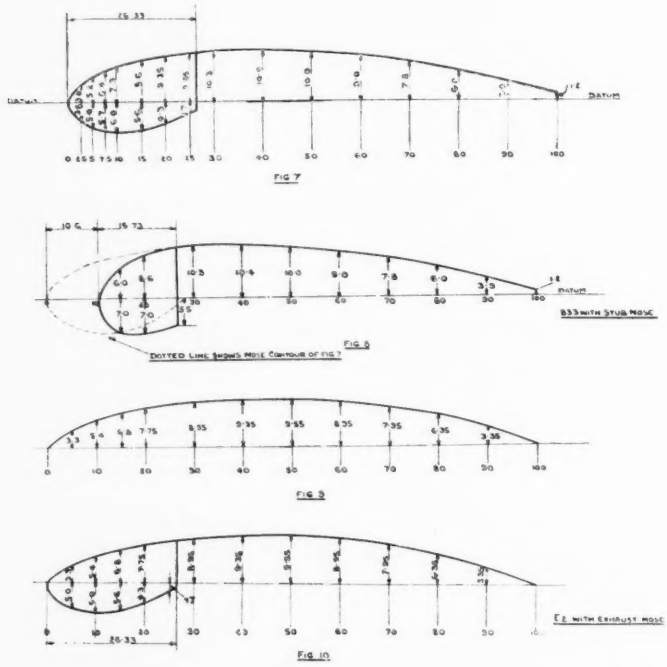


FIG. 8.

Fig. 9 shows the variation in drag of an engine and streamline nacelle fitted with a Townend Ring for various chord angles of the ring itself. The curves marked 1 relate to the ring when the midpoint of the chord lies in the plane of the cylinder centre line. Curves 2 and 3 relate to the same Townend Ring moved forward by successive steps, each of about 20 per cent. of the chord length, this chord length in the particular case being about 48 per cent. of the engine diameter. For the position 1 it will be seen that there is a range of chord angle from $-2°$ to $-6°$ over which the drag is practically constant, and that at $-8°$ the drag starts to rise very rapidly. For positions 2 and 3 the minimum drag has increased appreciably and the flat portion of the curve has disappeared, No. 3 showing a sharply marked minimum value of drag, the curve rising steeply on either side of this minimum.

The general characteristics shown for the lower set of curves without slipstream are retained by the upper set, which represents the conditions with an appropriate airscrew running at conditions corresponding roughly to climbing airspeed. With very few exceptions, it has been found that the presence of slipstream does not affect the relative merits of different ring arrangements.

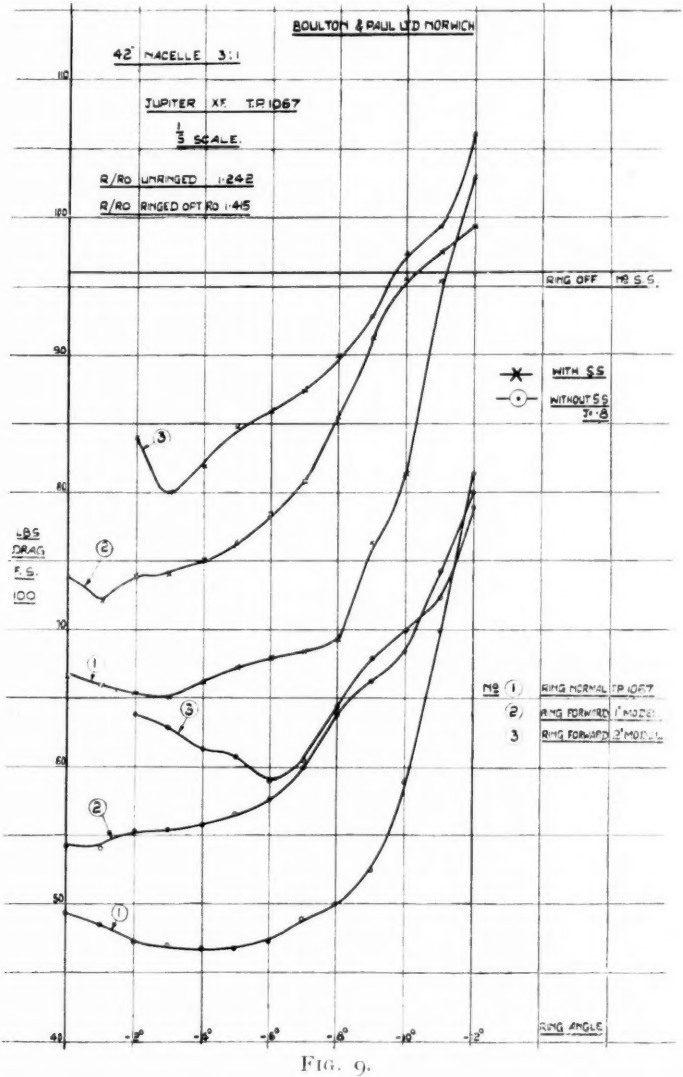


FIG. 9.

Fore and Aft Position of Ring

The curves of Fig. 9 also indicate the nature of the effect of changing fore and aft position of a Townend Ring relatively to the body. The results

relate only to one particular type of ring used on a particular form of body, and even for that case do not extend sufficiently far to prove that position 1 is the best possible. Experience, however, indicates that in nearly every case a ring which is placed with its chord extending equally ahead of and behind the cylinder centre lines will give better results than one placed in any widely different position.

Chord Length

The chord length required to produce a given degree of constraint on the tendency of the airflow behind the engine to break away from the body depends mainly on the lift coefficient which is developed by the ring section. Sections of the types previously illustrated, which have been found satisfactory, apparently develop, when used as Townend Rings, lift coefficients of the order of .5 to .6, and with these sections a chord length of approximately .5 of the engine diameter is found to give the maximum reduction in drag.

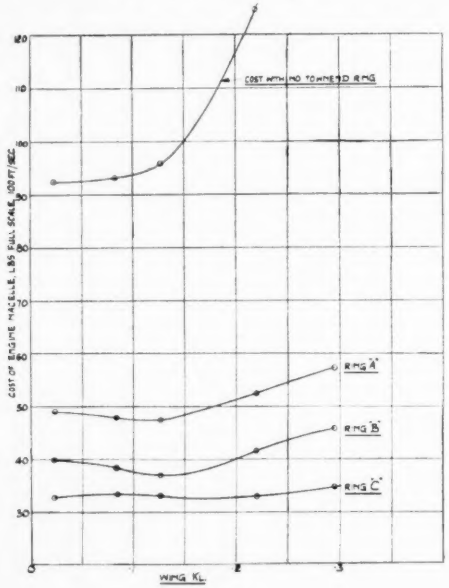


FIG. 10.

The flow over the nose of a body engine combination is necessarily curved, and change in chord length of a ring alters the effective angle of incidence between the ring and the airflow, therefore the effect of change of chord is not a simple effect. Fig. 10 shows the measured drag of a nacelle and engine mounted on a wing when fitted with three different rings. (*a*) Is a ring having a chord of approximately .33 engine diameter, (*b*) is a very similar ring with a chord length of .52 engine diameter, while (*c*) has a slightly increased chord .525 engine diameter and is fitted with a bulbous nose exhaust collector. The difference between (*b*) and (*c*) has little to do with chord length, but that between (*a*) and (*b*) indicates the kind of difference which attends on change of chord length.

This figure shows also the increase in drag due to the engine nacelle when no ring is fitted, and it will be seen that with no ring this drag increases very rapidly with increasing wing lift. With any of the rings, this increase in cost of engine as wing lift increases is very greatly reduced, and, within the range

covered by the figures, has completely disappeared for the best of the three rings, *i.e.*, (*c*). It may be remarked that it is a general characteristic of a good Townend Ring that it maintains its effectiveness over a considerable range of conditions.

Polygonal "Rings"

Fig. 11 shows two Townend Rings of identical section, chord length, and chord angle, made for use with the same nine-cylinder engine. Tested on a streamline nacelle the measured drag using the polygonal ring was found to be slightly less than that with the circular ring. For a nine-cylinder engine 54in. in overall diameter, the equivalent full-scale drags were 27lbs. for the polygon and 31lbs. for the circular ring, which is to be compared with 96lbs. with no Townend Ring, at an airspeed of 100 ft./sec. A very large number of tests have now been made in our wind channel giving a direct comparison between the performance of circular and polygonal rings of otherwise identical form, and used on identical engine-body combinations. In no such case has the polygonal ring given results inferior to the circular one, and in the majority of cases the polygon has shown a definite advantage. Tests made with the airscrew running show that slipstream does not adversely affect the superiority of the polygon.

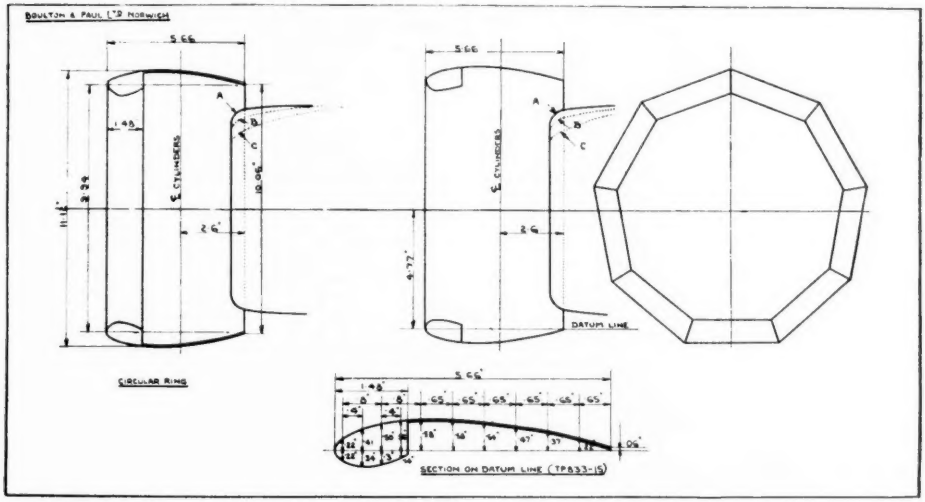


FIG. 11.

As a result of certain tests made in America (11) the opinion has been expressed that a polygonal ring is inferior to the circular ring. This opinion is, however, based on the comparison between a particular polygonal ring and of a number of circular rings of varying section and chord angle. The polygonal ring was of the variable angle type, and gave its best results at a chord angle giving an unnecessarily large engine clearance, and was therefore of larger overall dimensions than necessary. The tests to which I have referred above relate to rings of identical section, chord length, and chord angle, tested on the same model and there can be no doubt as to the superiority of the polygon ring under these conditions. The two rings shown in Fig. 11 have been tested full-scale on the same aircraft. The difference in drag shown by the model tests amounts to only 2 per cent. of the total drag of the aircraft, a difference which is not measurable by performance tests, but full-scale tests confirm that the polygon ring is in practice certainly not inferior to the circular type.

Body Shapes

It is obvious that any form of engine cowling can modify only the increase in resistance, due to adding an engine to a body, which might otherwise be of good shape over the section occupied by the engine. The increase in resistance, due to fitting any given engine, depends not only on the engine itself, but upon the characteristics of the body as a whole. To put a radial engine on to a large body of very poor shape may cause a relatively small increase in drag, and any cowling applied to the engine can affect only this small component of the total resistance. The converse is also true. If fitting a radial engine necessarily means a breakdown of the flow over the body, and to a high drag, there is very little incentive to the cleaning up of the body behind the engine. Development of practical types of low drag cowling for engines thus adds importance to the provision of the best possible body shapes.

So many practical considerations govern the design of body shapes that it is quite impossible to give any hard and fast rules as to the shape of body which should be employed with the Townend Ring. Fortunately, however, the performance of the Townend Ring itself appears to be influenced mainly by the form

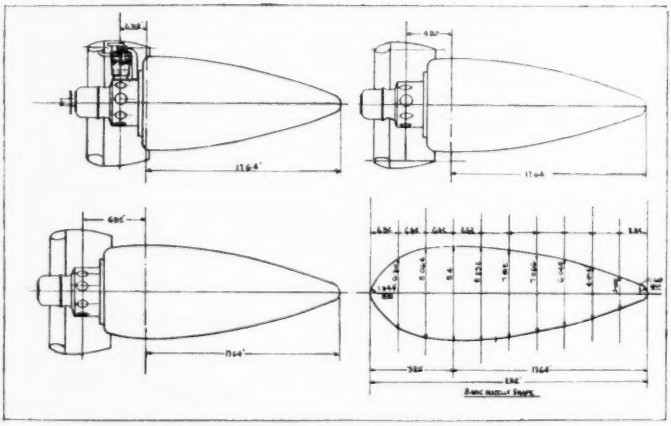


FIG. 12.

of the body for a short distance behind the ring only. Experience to date shows that for current type of radial engines the maximum reduction in drag with a Townend Ring can be secured if the body immediately behind the engine has a diameter of about .75 of the engine diameter and if the body lines over a distance of about one engine diameter behind the engine plate are reasonably fair and do not diverge or converge with abnormal rapidity. What the body form further from the engine may be, may greatly affect the total resistance of the body and engine combination, but will not greatly affect the saving in drag caused by the Townend Ring.

Fig. 12 shows three models of engines and nacelles which have been tested. The nacelles themselves are solids of revolution having the outline of the standard 3 : 1 streamline strut section and differ only in the position of the engine on the bodies relative to the maximum ordinate of the basic streamline. The diameter of this maximum ordinate was 0.78 of the maximum diameter of the engine. Of the three models tested the intermediate is slightly the best, both with and without the Townend Ring, but the differences between the three arrangements are not large. This intermediate arrangement is that which with

the polygonal ring gave a total full-scale drag for the 54in. diameter radial engine of 27lbs. at 100 ft./sec., which is so far about the minimum resistance which it has been found possible to obtain for a radial engine of these dimensions with any form of Townend Ring.

Although the tests relate directly to engines mounted on streamline nacelles in free air, experience shows that if the form of body immediately behind the engine corresponds reasonably closely to that of any of the three nacelles shown over a length equal to the engine diameter, the drag reduction caused by a given Townend Ring will be of the same order as that which the same ring would cause on the streamline nacelle.

Normally for best results the body section over the region above mentioned should be circular. If a polygon ring is used, a polygon body, sides parallel to those of the ring, is as good as, or slightly better than, a circular one. With either shape of ring considerable variations in body section have relatively small effects on the saving in drag caused by the ring, the total drag of the combination being influenced more by the change in drag of the body itself, the engine being supposed removed, than by any change in the effect of the ring.

Where aircraft are to be designed for use with a ring, there is usually little difficulty in providing a body shape which with a ring will give a close approach to maximum possible drag reduction. Where the ring has to be applied to aircraft already in existence, it is usually necessary to make the best of the existing body, and, where this is of angular section and abnormal lines, difficulty in finding an effective Townend Ring may be encountered.

Townend Rings and Interference

The effect of the Townend Ring on the drag of an engine is of the type of phenomenon usually described as "interference." Fig. 10 indicates clearly how a Townend Ring may reduce interference between a wing engine installation and the wing itself, and in cases where, as is usual, such wing engine interference is appreciable, a satisfactory Townend Ring will almost invariably greatly reduce the interference drag.

The Townend Ring itself is very sensitive to certain types of interference. If the flow over the outer surface of the ring is disturbed it may be caused to break away and local stalling of the ring section provoked. More than a very limited degree of such local disturbance is found to produce an effect which spreads round the ring circumference and very rapidly destroys the effectiveness of the ring. The most difficult cases of interference with the Townend Ring yet encountered are those in which interference between the ring and a closely approaching wing occur.

Fig. 13 shows at (*a*) and (*b*) conditions which almost inevitably lead to serious interference of this type and should be avoided; (*c*) and (*d*) which differ from (*a*) and (*b*) only in a relative vertical displacement of ring and wing, so that the leading edge of the wing definitely cuts the ring periphery instead of being nearly tangent to it, are free from this trouble and give satisfactory results. A variant of (*a*) in which the engine is dropped below the wing and the nacelle is separated therefrom instead of being built on to it, may be worse than (*a*) itself, and is only satisfactory when the engine is dropped far enough to give a large vertical gap between the ring and the leading edge of the wing. The arrangement (*e*) gives excellent results, but it is important not to move the ring and engine so far back that the leading edge must be mutilated to clear the engine itself.

(*f*) in this figure shows a case where interference between wing and ring was greatly reduced by cutting away a segment of the ring in way of the wing. Generally speaking, cutting of gaps in the ring circumference causes the ring to become almost completely ineffective. If, however, a member is provided which will serve to carry the general ring circulation across the gap the effect of

the interruption becomes unimportant. The case illustrated is one in which the wing serves to bridge the gap. The ring shown in Fig. 14 is one in which two machine guns were required to fire through the ring, which had to be cut away for this purpose. Rectangular boxes forming gun tunnels were built into the ring itself and produced no measurable ill effects.

The total resistance of a ring-cowled installation is very little affected by bodies which are within the ring itself. Circular struts for supporting the ring do not increase the drag as compared to streamline struts. Exhaust collectors within the ring have but a very small effect, which is often unmeasurable, and the effect of fitting inter-cylinder baffles, various types of air intakes, or the like, which do not protrude beyond the ring, is invariably small, and usually negligible.

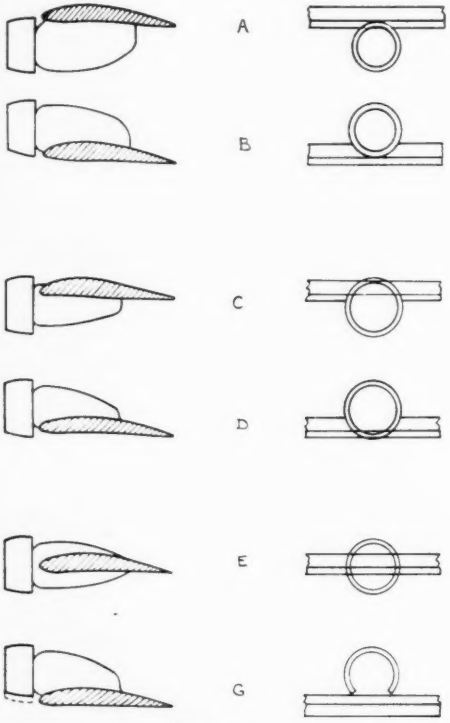


FIG. 13.

Cowling of the normal type surrounding the crankcase of the engine does not measurably affect the resistance, but may have an important effect in raising oil and crankcase temperatures, and should always be omitted unless this effect is desired.

Engine Cooling

Comparison of a typical Townend Ring with any other form of low drag cowling for use on a similar engine, indicates the probability that the ring will interfere less with cooling than will any of its present-day competitors. The necessary development of a lift force by the ring sections and the circulation round the ring which this implies, involves some reduction in the velocity through

the ring as compared to that outside it. This reduction in velocity cannot be of any great magnitude and would not be expected to account for any serious effect on cooling.

Practical experience has shown that the Townend Ring does give cooling superior to that of other available types of cowling for radial engines capable of substantially reducing the drag of those engines. Mr. Fedden has published results (10) which show that satisfactory cooling can be obtained with a Townend Ring on a particular engine and aircraft combination to which the application of a complete cowling of the N.A.C.A. type was impracticable because it caused overheating. There is a considerable fund of experience in America indicating that, whereas this complete type of cowling can normally be employed successfully on ungeared engines, it leads frequently to difficulties with cooling when it is applied to geared and particularly to geared and supercharged engines. The

FIG. 14.

Townend Ring with rectangular gun tunnels (just visible at top of ring).

restricted frontal opening of the complete N.A.C.A. cowling is in the region mainly affected by airscrew boss shielding, and the area so affected is greatly increased, as has already been pointed out, when a large diameter slow running airscrew is employed. The Townend Ring, with its wider frontal aperture, is less affected in this way.

Direct measurements of the air velocity close to the sparking plugs of a nine-cylinder radial engine have been made in flight (Ref. B. and P. tests 2161 and 2173) both with and without Townend Ring, using pitot heads and hot wire anemometers. The pitot heads show a small rise in velocity of the order of 5 per cent. when the ring was fitted, the hot wire anemometer, on the other hand, showed a reduction of the same order. Many explanations for this discrepancy are possible, the most probable being that the Townend Ring had substantially changed the direction of air flow, to which the hot wire anemometer would be insensitive. The hot wire anemometer being a direct method of measuring cooling, and only an indirect measure of air speed, the results indicate a small loss in effective cooling. A large number of tests have also been made by my firm on 1/5th scale engine models in the wind channel. These models have been provided with one, or in some cases, all, of the cylinders, electrically heated; these heated cylinders being fitted with thermo-couples.

The electrical input to the cylinders being maintained constant the steady temperatures reached by the hot cylinders will indicate the relative cooling with various forms of cowling. It is obvious that, by calibrating the hot cylinder as an anemometer, the results may be expressed in the form of effective cooling

velocities, as a percentage of that obtaining with the uncowled engine, for example. All such tests have shown a definite reduction in the effective cooling as a result of fitting a Townend Ring. The magnitude of the effect varies over a fairly wide range with varying installations and it has not been found possible to establish any definite co-relation between cooling and any specific characteristic of the Townend Ring. It can, however, be said definitely that there is no direct connection between drag and cooling such that a low drag installation is necessarily one giving poor cooling.

Unfortunately it has been equally impossible to co-relate results of these model cooling tests with full-scale results. One particular ring cowling which has been reported by the engine makers to give satisfactory cooling, tested by the hot cylinder method above described, shows a reduction in effective cooling

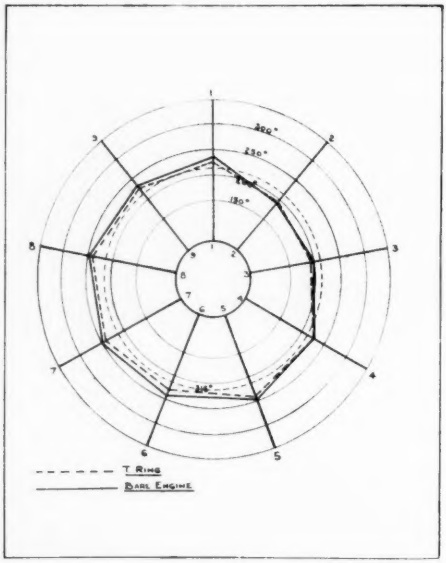


FIG. 15.

velocity to 67 per cent. of the cooling velocity over the same engine when the Townend Ring is removed. Another Townend Ring, which was accused of "cooking" the engine within it, showed a cooling velocity on model tests equal to 95 per cent. of the free air cooling velocity.

Examination of the very considerable amount of data now available regarding engine cylinder temperatures under actual operating conditions throws a good deal of light on the discrepancy in question, but has not yet supplied any complete explanation.

Fig. 15 shows temperatures measured on the rear face of the cylinder heads of a nine-cylinder radial engine running on the test bed with the standard fan and wind tunnel cooling arrangement. Two curves, which are very nearly identical, relate to the temperatures with and without a Townend Ring. The absence of any appreciable difference in temperature under the two conditions may be explained by the artificial cooling conditions. Attention is directed, however, to the irregularity of temperature distribution round the engines, the maximum variation between individual cylinder temperatures being about 50°C.

Fig. 16 shows cylinder temperatures measured on an engine of the same type during climb, with and without Townend Rings, on the same aircraft.

The average temperature when the Townend Ring is fitted has obviously increased appreciably. The irregularity of temperature distribution around the engine is more marked, both with and without ring, than is shown in the test bed case. Repeated tests under similar conditions, using the same engines and aircraft, have shown that this irregularity, though always present, varied from flight to flight, and it was quite usual to find that a cylinder which had developed an abnormally high temperature on one flight remained abnormally cool on the next.

Fig. 16 relates to a type of engine which had had its power output boosted to about the limit of its cooling capacity when used without a Townend Ring, and even in this condition at the relatively slow climbing speed used in this particular case the cooling could not be regarded as completely satisfactory.

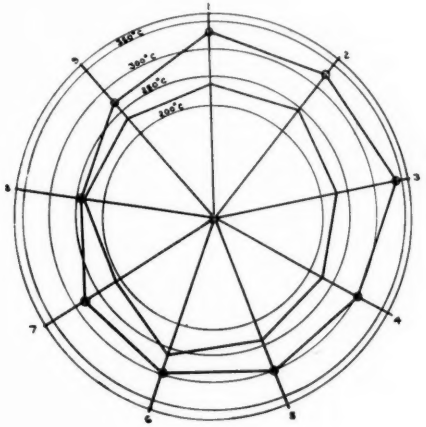


FIG. 16.

Fig. 17 shows in a slightly different form the results of similar tests on an engine of generally similar type. In the bottom curves the temperature of No. 3 cylinder with the Townend Ring is definitely unsatisfactory. Tests were accordingly made with inter-cylinder baffles around cylinder No. 3 which also half encircled cylinders Nos. 2 and 4. As the second set of curves show, the temperature of No. 3 cylinder dropped from 285°C. to 225°C. No. 2 cylinder, only half baffled, showed practically the same temperature as No. 3, with the complete baffling. It may be noted that No. 1, complete unbaffled, dropped in temperature between the two tests by nearly 70° and No. 5, also unbaffled, by 50°C. Following this test all cylinders except No. 6 were fitted with half baffles of the type which had apparently effectively cooled No. 2. On a third test, indicated by the upper curve, the temperature of No. 3 had returned to practically its original high figure, and it will be obvious that no sort of connection can be established between the presence of baffles and cylinder temperatures. Further, the irregularity of temperatures round the engine is very obvious, and is found, in a reduced degree, even where cooling is considered satisfactory. Wherever

the fitting of Townend Rings has led to actual overheating, investigation indicates that this irregularity of cylinder temperatures becomes very marked indeed.

Increase in general temperature, marked by such violent irregularities in temperature distribution, can obviously scarcely be attributed to any direct effect of the Townend Ring on the effective cooling velocity over the engine, and many explanations of the effect have been considered. Of these, the one which seems to have the best foundation, is, that the very considerable change in the direction and general turbulence of the airflow past the engine, caused by the ring, may disturb air intake and carburettor conditions and lead to variations in mixture strength and/or to irregular gas distribution.

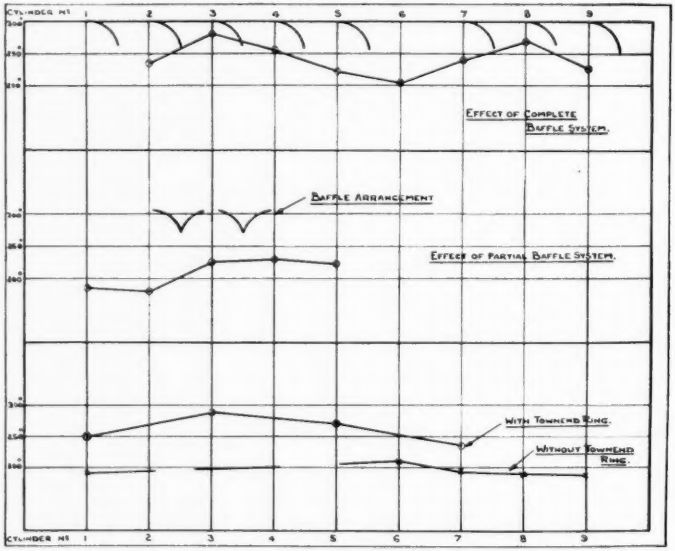

CYLINDER NO 1 2 3 4 5 6 7 8 9
EFFECT OF COMPLETE BAFFLE SYSTEM.
BAFFLE ARRANGEMENT
EFFECT OF PARTIAL BAFFLE SYSTEM.
WITH TOWNEND RING.
WITHOUT TOWNEND RING.
CYLINDER NO 1 2 3 4 5 6 7 8 9

FIG. 17.

A Boulton and Paul Townend Ring, fitted to an aircraft of foreign manufacture, was found to give a very satisfactory increase in performance, but to cause a serious rise in cylinder temperatures, irregular running of the engine, and, after a period of operation, even the cutting out of the engine. A series of experiments with carburettor adjustments, and with various forms of air intake, was put in hand, and definite improvements in engine running resulted. Finally, the carburettor originally fitted to the engine was replaced by one of totally different type. This change cured all the troubles encountered previously, and the engine temperatures measured in flight with the Townend Ring fell to figures below those obtained with the original cowling of the engine, which was of the ordinary crankcase and spinner type.

I understand that on one occasion at least, the Bristol Company have found during the course of test bench running, that the fitting of a Townend Ring weakened off the mixture supplied to the engine, there having been no alteration in carburretor adjustment or air intake between the tests with and without Townend Ring. I should be very greatly interested to hear the opinion of Mr. Fedden as to the bearing which such effects have on the general problem of engine cooling with low drag cowlings. Our own experience leads me to the

firm belief that there is a field for useful investigation into the effects of the Townend Ring on air intake and carburettor conditions, and that such investigations lie rather in the field of the engine designer than of the aircraft designer.

Serious cooling difficulties attendant upon the fitting of the Townend Ring rarely arise, except in the rapidly-diminishing number of cases in which the cooling margin of the engine, even without low drag cowling, is small. The designer of radial engines has realised the importance of modern low drag cowlings and of providing his engines with cooling capacity which will be adequate when such cowlings are fitted, consequently such difficulties are steadily growing rarer.

Where irregular temperature distribution occurs, and there is strong evidence that it occurs to some extent in all air-cooled engines, the cooling which has to be provided is that which will keep the hottest cylinder down to permissible limits; and the analysis of the reasons for such irregular temperatures and methods for their cure should be of the utmost interest to the engine maker himself, since they are one method by which effective cooling can be appreciably increased.

Townend Rings on Pusher Engines

A Townend Ring will effectively reduce the resistance caused by an engine fitted at the rear of an aircraft body. For use under these conditions the ring chord angle requires to converge fairly rapidly to the rear, whereas for the more usual type of installation the convergence is almost invariably in the opposite sense. A ring used on such an installation is subject to a large down-wind force, whereas on the normal installation there is a large up-wind force. A reduction in drag in this case must be associated with large increases in the pressure on the rear end of the body within the ring, but the essential characteristic of the Townend Ring—that of producing a downwash which prevents the flow from breaking away—remains unaltered.

Relatively little use has been made of Townend Rings on pusher installations, and it appears that the saving in engine drag which is possible in this case is considerably less than that obtainable with the more usual installation, although it is still very substantial. Reports of results obtained with full-scale installations of this type suggest that a Townend Ring on an engine at the rear of the body has the effect of rather improving the cooling than otherwise.

In tandem installations, Townend Rings have been used on both front and rear engines. It appears that in these cases the reduction in drag which is possible is mainly that due to the front ring, the rear ring contributing only something of the order of one-third of the total saving, but investigation of such cases has been relatively limited, and the results so far obtained do not necessarily indicate the possible limits.

In certain cases, the use of a Townend Ring on the front engine of a tandem pair is stated to have very considerably improved the cooling of the rear engine—a point of very considerable importance. In view of the effect of the ring in preventing a breakaway of flow behind the engine, this is not altogether surprising.

Model Tests and Full-Scale Results on Townend Rings

The Townend Ring owes its origin to investigations carried on in the wind channel with small-scale models. There is inevitably some doubt as to the direct applicability of the results of such tests to the prediction of performance for the full-scale aeroplane.

Full-scale tests of Townend Rings have now been made in sufficient numbers to place it beyond doubt that the effect shown by small-scale models also occur in the full-size aeroplane, and there is enough evidence to show that the magnitude of the saving in resistance shown by model tests is of the same order as that

indicated by full-scale performance tests. A good deal has been made in one or two cases of an apparent discrepancy between model tests and full-scale results in cases where the model has appeared to promise a much larger increase in performance than the full-scale tests have indicated, and hence, the deduction has sometimes been drawn that there is an adverse scale effect on Townend Rings generally. If the evidence as to the reliability of model tests generally is examined by comparing the performance of aeroplanes as they are predicted from model tests, and the performance shown by the same aeroplanes in flight, it would, I think, be generally found that there was equal reason for suggesting an adverse scale effect as being a general phenomenon, and not one peculiar to the Townend Ring.

Models used for Townend Ring investigations require to be to a fairly large scale. Our own experience indicates that a scale of one-fifth, with a wind channel speed of 60 ft./sec., is sufficient for most purposes, but that it is dangerous to go to a much smaller scale. We have actually made models as large as two-fifths scale and have been unable to detect any substantial difference between this and one-fifth scale. On the other hand, if the scale be reduced to one-tenth the results may be extremely misleading, the drag of a Townend Ring cowled engine at one-tenth scale being always very considerably higher than that given by the one-fifth scale models. This is mainly due, apparently, to scale effect on the drag of the engine itself, for if a one-tenth scale model be made fully representative of the engine, its drag at 60 ft./sec. will be very much higher than that of a similarly complete model on one-fifth scale.

Mr. Townend (R. and M. 1267) has described a case where an adverse scale effect on a Townend Ring was measured. This ring was of very short chord and moderately thick symmetrical section, a type generally very sensitive to small changes in conditions. Our own experience has not shown any similar case.

In the same R. and M. Mr. Townend reports tests indicating that no large scale effect is to be expected from engine cylinders. These tests relate to a change in scale from about $\frac{1}{4}$ to about full scale, and agree with our experience that no important scale effect occurs above 1/5 scale models.

We have tested the drag of 1/10 and 1/5 scale model rings alone, with neither engine nor body in position. As the ring is an endless aerofoil the results should have given profile drags only. The results are rather curious.

The circular and polygonal rings of Fig. 12 give the following results:—

		1/10	1/5
Circular	...	18.26	17.72 lbs. F.S. @ 100 ft./sec.
Polygon	...	19.60	19.4 ,, ,, ,, ,,

When the bulbous nose was removed, leaving a normal plate type section, the results were:—

		1/10	1/5
Circular	...	31.41	22.73 lbs. F.S. @ 100 ft./sec.
Polygon	...	28.10	21.04 ,, ,, ,, ,,

A circular plate ring of slightly different section gave drags of 30.4 lbs. at 1/10 and 25.95 lbs. at 1/5 scale.

These figures show no reason for expecting an adverse scale effect on the ring itself.

In R. and M. No. 1504, reference is made to tests which showed that for 1/5 scale model, the saving in drag due to a ring fell from 26.7 lbs. at 50 ft./sec. to 23.8 lbs. at 120 ft./sec. So far as it is possible to trace from the details which have been published for this case, it appears that the drag of the complete model fell from 167.7 to 149.4 lbs. over the speed range, the saving due to the ring remaining constant at 15.9 per cent. of the total drag. The ring here shared in the general scale effect on the complete model, and the percentage change in performance which would be predicted from the model results would be independent of scale of test.

It is very common practice to represent the engine on small-scale models by a conventionalised dummy engine which is arranged to give the known, or assumed, drag of the real engine. Such conventionalised models cannot safely be used with a Townend Ring on any scale, because the change in drag caused by a Townend Ring depends on the exact pattern of the air flow caused by the engine, and not by the engine's absolute resistance. The representation of engine installations by conventionalised models is usually extended to cover cowling details, and air passages through cowlings are either not represented at all, or are replaced by a few passages drilled through the body block. Tests which have been carried out comparing the resistance of a representative model of a complete engine with the normal type of cowling accurately represented, invariably show very much higher drags for the normally-installed engine than are given by the usual type of conventional representation.

At least one case is on record in which the drag of an aeroplane was assessed from a model of this type and from the performance of a model airscrew running in position. In this case it was found necessary to conclude that the b.h.p.

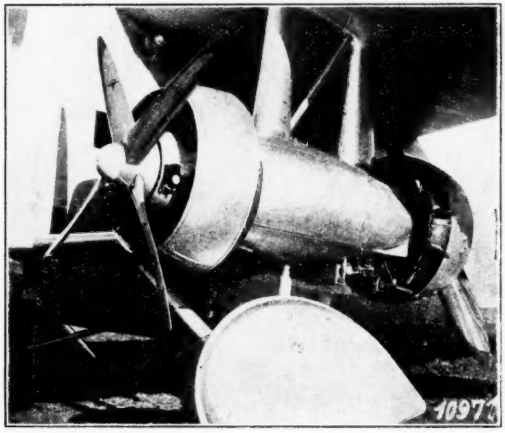


FIG. 18.

Tandem Townend Rings on Dornier Type Do.K.

developed by the engine in actual flight was 15 to 20 per cent. below the test bed b.h.p. I personally have very little doubt that in this case the conventionalised engine and cowling of the model very seriously underestimated the total resistance. The same model was fitted with a Townend Ring and it was computed that the Townend Ring should produce, full scale, an increase in speed of 18 m.p.h., whereas full-scale tests show that the increase was about 7 m.p.h., and hence it was concluded that there was a large scale effect on the Townend Ring.

A further exploration of this case led to the conclusion that the apparent discrepancy between the model results and the full-scale tests was far smaller than had originally been computed, this conclusion, however, still resting on the assumption that the engine developed considerably less power than it should have done under the actual conditions of flight.

If in this case it were assumed that the drag of the machine without Townend Ring is that which would correspond to the makers' rated b.h.p. for the engine under the conditions of flight, and to a value of airscrew efficiency reasonably to be expected, the discrepancy between predicted and measured per-

formance is reduced to something under 2 m.p.h. on an aircraft with a top speed of over 170 m.p.h., a difference which I consider to be well within the probable inaccuracy of measurement of aircraft speeds full scale.

In this case, and in one or two other cases which have come to my notice, I feel fairly satisfied that a great proportion of the apparent discrepancy between predictions from model tests and results realised in actual flight arise because the assumed total resistance of the aircraft deduced from model tests has been seriously far from the truth. Too low an estimate of the total resistance of the machine will exaggerate the change in performance which should result from a given reduction in that resistance, such as may be produced by fitting a Townend Ring. The use of conventionalised models of engines usually seriously underestimates the drag of those engines when Townend Rings are not fitted, has a reduced effect on the saving caused by the Townend Ring, and leads generally to an over-optimistic estimate of the increase in speed which the ring can produce.

Many comparisons between the results of model tests made by my firm and of full-scale tests showing the effect of Townend Rings are available. Where the full-scale tests show directly the change in performance due to the fitting of the Townend Ring, the correspondence between model result and full-scale test has generally been very satisfactory. Where estimates of the effect of fitting

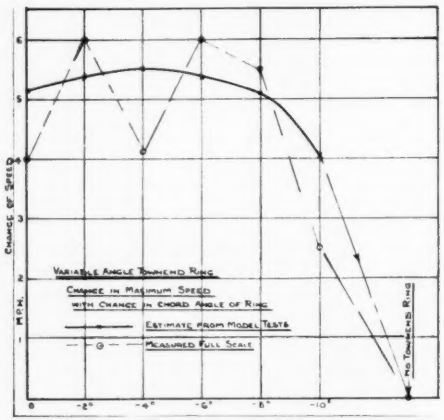


FIG. 19.

Townend Rings have had to be made from the estimated drag of the unringed machine, no check on the real drag being available from a full-scale test with the ring omitted, the maximum speed obtained has frequently fallen short of the designer's hopes, but this characteristic is not confined to aircraft with Townend Rings, and should not be taken as evidence of their failure to produce, full scale, the saving in drag shown by model tests.

In a figure shown earlier, the model results of varying the chord angle of the Townend Ring were shown. The figure in question related to three different fore and aft positions of the ring relative to the engine, of which the position identified by 1 on the curves showed a range of chord angle of from -2 to -6 in which the resistance changed very little indeed, the minimum resistance, however, occurring at $-4°$.

In order to obtain, if possible, full-scale confirmation of these results, a variable angle Townend Ring, precisely similar to the model, was tested full scale. It was found impossible in the full-scale ring to give the same range of angular adjustment as had been tested on the model, and the full-scale tests therefore extended over a range of from 0 to $-10°$ only. This range was, however,

sufficiently wide to show whether the apparent long range of substantially constant drag, indicated by the model, existed in full scale.

Fig. 19 shows the estimated variation in performance with ring angle, and that measured full scale. It should be noted that the full-scale results plotted

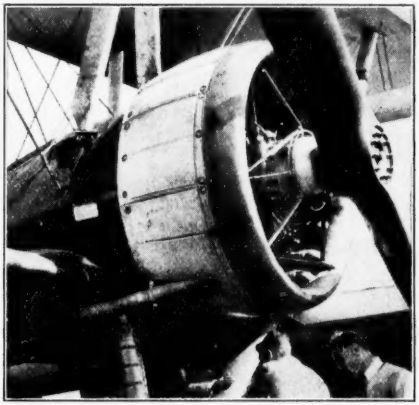


FIG. 20.
Boulton and Paul combined exhaust collector and Townend Ring (circular type).

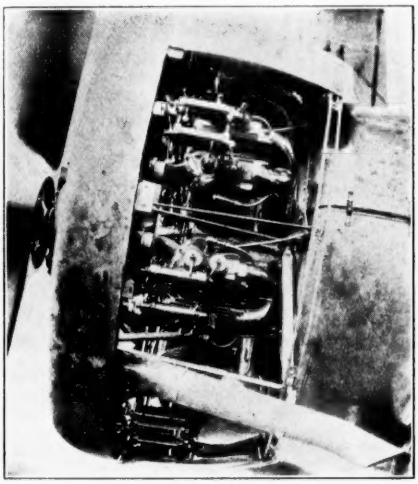


FIG. 21.
Boulton and Paul combined exhaust collector and Townend Ring. Panels removed for access to engine.

are the mean of six speed readings for each ring chord angle. The total estimated change in speed between no Townend Ring and Townend Ring at its most effective setting is 5.5 m.p.h. The variation between the various measured full-

scale speeds at each individual ring angle vary between 2 and 7 m.p.h. I do not regard these particular tests as showing any abnormal degree of variability, and I think that any attempt to determine the true top speed of an aircraft of a reasonably high performance with an accuracy greater than that attained in these tests is likely to be attended by many very serious difficulties. Where Townend Rings or any other device is accused of failing to give the results promised by model tests because full-scale performance falls short of that expected by three

FIG. 22.

Boulton and Paul polygonal exhaust collectors and Townend Rings on Bristol Pegasus engines.

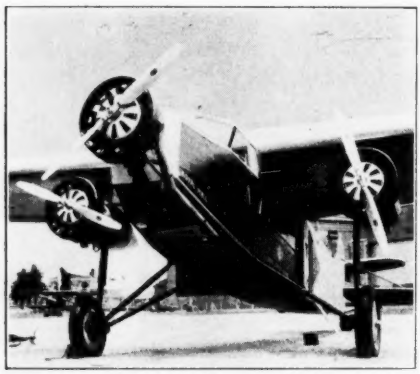


FIG. 23.

K.L.M. Fokker F XVIII, Pratt and Whitney Wasp engines.

or four miles an hour, I feel that the probable accuracy of the full-scale tests, and of the methods of prediction used, require careful scrutiny before they are accepted as conclusive.

Total Power Plant Drag with the Townend Ring

It may be interesting to compare estimates of the drag necessary for cooling with results which have actually been obtained with the Townend Ring. The

estimate made by Pye, which has been earlier mentioned, that at 150 m.p.h. about 1.5 per cent. of the total engine output must necessarily be used in providing engine cooling when the temperature difference available for heat transfer is 180°C., relates only to ideal conditions which we can scarcely hope to approach in the air-cooled engine, even if the suggestion which has once been made of using streamline sections instead of circular ones for engine cylinders were found to be practicable.

FIG. 24.
Armstrong Whitworth Atalanta.

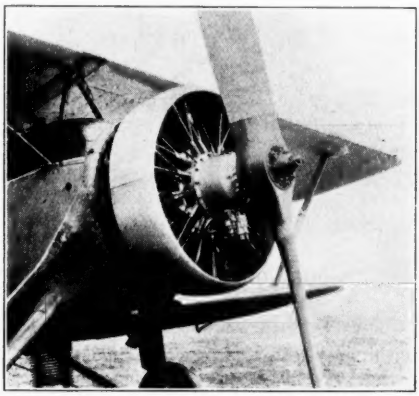


FIG. 25.
Townend Ring Armstrong Siddeley Panther engine, Atlas aircraft.

McKinnon Wood, in a paper to which reference has also been made, has suggested a method of cooling which is certainly practicable, involving the enclosure of the cylinders in ducts which confine the cooling air flow to a path closely following the cylinder contour and embodying a fan so that the cooling is not dependant on the air speed of the aircraft. The use of the fan is indicated as preferable on account of the claimed self-regulating characteristics of this cooling system, and if aircraft of much higher speeds than are at present common are to be attained with engines having characteristics not greatly different from

those of existing types, fan cooling may become necessary and does not appear to be inconsistent with the use of ring cowling of the Townend type.

Assuming a mean temperature difference of 250°C. between cylinders and cooling air, McKinnon Wood estimates that, allowing for fan losses, 4 per cent. of the b.h.p. will be used in providing cylinder cooling alone. A mean temperature of 250°C. between cylinders and air is certainly not available in the majority of engines to-day in service. The maximum permitted temperature at a position on the cylinder heads, which is certainly above the mean temperature of the cylinders as a whole, is normally between 215° and 235°C. For a mean temperature difference of 200°C., McKinnon Wood gives the power absorbed in cooling cylinders as 10 per cent. of the b.h.p. Even 200°C. is almost certainly higher than the mean difference which can be permitted with engines of existing type, but we may take this figure of 10 per cent. as representing about the figure which might be achieved in practice with a cooling system of the type suggested.

FIG. 26.

P.Z.L. P.XI single-seat fighter, Mercury engine.

The best result within my knowledge which has so far been obtained, using a Townend Ring, is that given by 54in. diameter nine-cylinder radial engine mounted on a streamline nacelle of 42in. maximum diameter, fitted with a polygonal Townend Ring, and having a total drag at 100 ft./sec. of 27lbs. This result has already been referred to (Fig. 11).

The same engine, the same ring, and a nacelle of similar dimensions, have been mounted on the wings of an aircraft for an increase in drag equal to that of the free air nacelle, *i.e.*, 27lbs. This installation has been flight tested and gives satisfactory cooling of cylinders, of crankcase, of oil, and provides an exhaust system which effectively cools the exhaust and provides a considerable degree of exhaust silencing. In this connection I would mention that it has always been the practice of my firm to use oil coolers of the surface type which form part of the body or nacelle surface, and that the drag of these oil coolers is included in the drag of the nacelle above referred to.

With an engine developing a maximum b.h.p. of 480 at 4,000ft., the speed of the aircraft fitted with this installation was 140 m.p.h. true (132 i.a.s. at 4,000ft.), and the power absorbed by a resistance of 27lbs. at 100 ft./sec. at this speed is 43.5 h.p. or 9 per cent. of the engine b.h.p. When an engine of the same overall dimensions and type, but supercharged to give 600 h.p. at 5,500ft., was fitted in place of the lower-powered engine, the speed of the aircraft increased to 160 m.p.h. true (148 m.p.h. indicated at 5,500ft.), the engine installation drag being unaltered, and the power absorbed in overcoming engine drag became 54 h.p.—still 9 per cent. of the total.

FIG. 27.

Morane Saulnier, Type 222.

The Townend Ring fitted increased the speed of this aircraft from 288 to 312.5 km.h. at 4,000 m. according to S.T.Ae. tests.

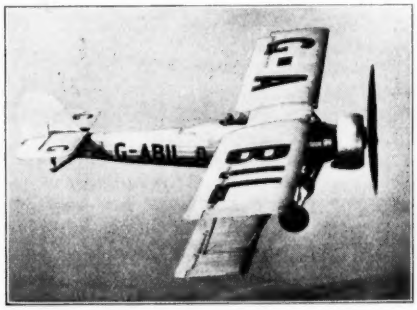


FIG. 28.

Vickers Vespa Pegasus engine, which set up a height record of 43,976ft.

Allowing for airscrew efficiency, the drag of the engine installation in this case at top speed is about 11.5 per cent. of the total drag of the aircraft.

In these examples the whole of the drag due to adding the nacelle and engine to the wings of the aircraft has been treated as power plant drag, which is proper. When the body which follows and fairs off the engine serves to accommodate crew and load, and would be necessary even were the engine not present, the drag due to the necessary body cannot be regarded as engine drag. In such cases the increase in drag caused by power plant may be appreciably less than in the examples above considered.

I understand that Messrs. Armstrong Siddeley Motors, Limited, have measured a total drag of 35lbs. at 100 ft./sec. for the fuselage, engine and Townend Ring of a military machine with open cockpit, wind screen and pilot. The engine in this case was a Jaguar capable of developing about 500 h.p. at sea level. This is 8lbs. in excess of the nacelle figure above quoted, and it is certainly not to be expected that the resistance of the fuselage alone, engine removed and a faired nose substituted, could reach so small a figure as this. The drag to be attributed to the engine in this case must therefore have been less than in the examples which I have considered.

It is, however, obvious that with engine temperatures which are to-day permissible and at speeds of flight which are to-day normal, a Townend Ring will reduce the power expended on overcoming the total resistance of a power plant to a value equal to or less than that estimated by McKinnon Wood as necessary for cylinder cooling alone, when using cylinder temperatures which are, if anything, higher than those actually available. With the arrangement which McKinnon Wood has proposed oil cooling, exhaust system, and air intakes will still have to be provided, and in practice would make an appreciable increase in the total power required to overcome engine drag.

If increases in cylinder temperature to figures such as he has contemplated do become available the result will be the development of increased output from

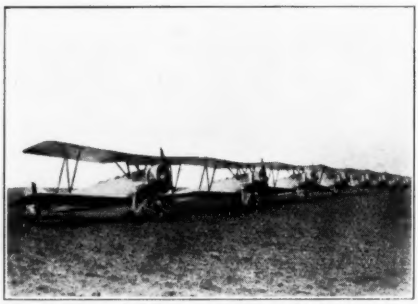


FIG. 29.

A batch of Avro Tutors with Townend Rings.

engines of a given overall diameter, and of a drag which, when fitted with the Townend Ring, will not be appreciably affected by any factor other than the overall diameter. Consequently the Townend Ring stands to gain from such increases in temperature equally with other possible forms of cooling system.

Future Developments

Despite the length of this paper I have only been able very cursorily to examine the main problems which have influenced the development of low drag cowlings. I have, I hope, been able to indicate that these problems are very involved and, particularly as regards the Townend Ring, that a very large number of factors influence performance both in respect of drag and of cooling. The work with which I have been particularly associated in the development of the Townend Ring has necessarily been confined mainly to discovering arrangements which could practically be applied to specific engines and aircraft with the maximum advantage, and it has only been possible to investigate general principles to a very limited extent and as a by-product of essentially " ad hoc " experiments.

The solution of many of the problems involved in obtaining the best possible results from a Townend Ring can only be achieved by co-operation with the engine designers, and I am glad to be able to place on record my appreciation of the way in which the engine maker has in fact directed his energies towards producing power plants which are capable of making good use of modern low drag cowlings.

I wish to acknowledge the assistance in the preparation of this paper to the staff of Boulton and Paul, Ltd., and particularly Captain W. H. Sayers.

I have further to thank the Air Ministry for permission to refer in the paper to the results of tests which have been made on their account, and also Messrs. Armstrong Whitworth Aircraft, Ltd., A. V. Roe and Co., Ltd., Vickers (Aviation), Ltd., K.L.M. Air Lines, Aeroplans Morane-Saulnier, Dornier Metallbauten Gmbtt, and Panstwowe Zacklady Lotnicze, who have supplied photographs and data regarding aircraft of their manufacture fitted with Townend Rings.

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Discussion

Mr. A. H. R. Fedden (F.R.Ae.S.): He congratulated Mr. North upon the thorough manner in which he had reviewed the important and interesting subject of engine cowling. Mr. North was one of the first people in this country to appreciate the possibilities of drag reduction of air-cooled radial engines by ring cowling, and had completed much valuable work in this direction.

Mr. Fedden understood from Captain Barnwell's wind tunnel investigations that there was no engineering difference between the forms of external cowlings known as N.A.C.A. and Townend Rings, and that all our model tests had shown that any reduction in drag, due to the fitting of an external cowling round a radial engine, was entirely due to a forward component of air force on this cowling, and was invariably accompanied by an increase of drag on the rest of the model. Assuming that these wind tunnel tests were correct, he favoured the N.A.C.A. cowling, with suitably proportioned baffles to the cylinders, as being a useful combination in certain types of machines.

Perhaps Mr. North's remarks on the N.A.C.A. cowling were somewhat severe when he had said that cooling difficulties arose with geared and supercharged engines. The latest "Douglas" high-speed passenger machine was powered by two geared and supercharged 700 h.p. "Cyclone" engines, and it was maintained that without the N.A.C.A. cowling it would be impossible to cool adequately under the particularly arduous test conditions which the Department of Commerce tests called for. This machine had to take off from an aerodrome at an altitude of 4,943ft. with one engine out, and to climb over 8,000ft. with manifold pressures rising as high as 3lbs. per sq. inch.

What had not been fully realised in this country was the importance of correctly designed inter-cylinder baffles and the great effect of fuselage shape. As Mr. North had aptly pointed out, there was little slipstream cooling from a geared airscrew, and there was still less with American V.P. airscrews, where the hub was bulky and the blades had cylindrical shanks for some distance outside

the hub. He thought that American engineers were inclined to regard all their cooling as being induced, and with a properly-designed exit annulus and fuselage, there was undoubtedly an appreciable extractor effect. Given this, it remained so to control the air that it passed only over the fins.

The great importance of the fuselage shape had recently been demonstrated most convincingly by a test in which a given N.A.C.A. cowled engine cooled adequately on a machine with nicely faired nacelles; but, when the same engine and cowling were installed in another single-engined machine with an unsuitable body shape and humps, the engine overheated very seriously.

Another point of interest was that velocity measurements, in the neighbourhood of the cylinder barrels, might prove unreliable, and in the United States it was usual to use the difference in total head in front of and behind the inter-cylinder baffle as a measure of cooling air speed. In the case mentioned, the differential head was 4ins. of water during climb at 100 m.p.h. A.S.I. with the correct fuselage, and only 1½ins. of water at the same speed on the second machine. In level flight cruising, the differential head was 12ins. of water on the first machine. It was interesting to note Mr. North's statement that struts, cylinder baffles, etc., within a Townend Ring, had a negligible effect on the total drag, and further information on this point would be appreciated. Mr. Fedden would be glad to feel that this was so; but he suggested that the statement was contrary to the results from practical full-scale tests made in this country and America, where it had been found that inter-cylinder baffles improved cooling but increased drag with a Townend Ring, but that they improved cooling and did not increase drag with an N.A.C.A. cowl, in front of a properly proportioned body.

Whilst fully appreciating the value of the Townend Ring, and acknowledging the force of Mr. North's remarks regarding field of vision, field of fire for forward guns, etc., it was worthy of note that whereas Townend Rings were used to some extent in the United States, more generally on single-engined pursuit machines, the tendency with the latest high-speed machines was to have complete N.A.C.A. cowling, especially where there were two engines mounted in wing nacelles. It was felt that the N.A.C.A. cowling was more valuable than the Townend Ring from the point of view of drag, and that, provided the fuselage was correctly designed and suitable inter-cylinder baffles were installed, the engine could be cooled more satisfactorily.

As proof that the N.A.C.A. cowling did exert a forward component, the Wedell-Williams Racer, at Chicago this year, had had to come down when travelling at over 300 m.p.h. because the cowling had definitely moved forward and was in close proximity to the propeller.

With reference to Mr. North's remarks on the effect of ring cowling on carburation, it was agreed that any form of cowling round a radial engine altered the configuration of the air stream, and that it was necessary to have a design of carburettor in which the pressure balance effects were not altered; this matter had been dealt with on the carburettors of recent type Bristol engines.

He also suggested that, in regard to the picture which Mr. North had shown of a foreign single-seater with ring cowling, if the air intake had been placed outside the Townend Ring, cooling and the functioning of the engine might have been satisfactory.

Mr. Fedden was fully alive to, and in agreement with, Mr. North's view in regard to the importance of suitably ring cowling air-cooled radial engines, but he was hoping that the aircraft designer would give as much attention to the body immediately behind the cowling as to the cowling itself. For the future, he suggested that controllable cowling would be absolutely necessary, and it was interesting to note, in connection with the patent applications given in the paper, that Patent Specification No. 11315 was granted to Mr. Granville Bradshaw in 1917, which provided for a cowling practically identical with the N.A.C.A.

type, and with controllable flaps to meet the climbing conditions, combined with a really close cowling with inter-cylinder baffles.

Mr. Fedden considered that the type of polygonal ring cowling combining exhaust manifold, developed by Mr. North, was excellent from a silence point of view, and was also better than the present accepted forward type of exhaust

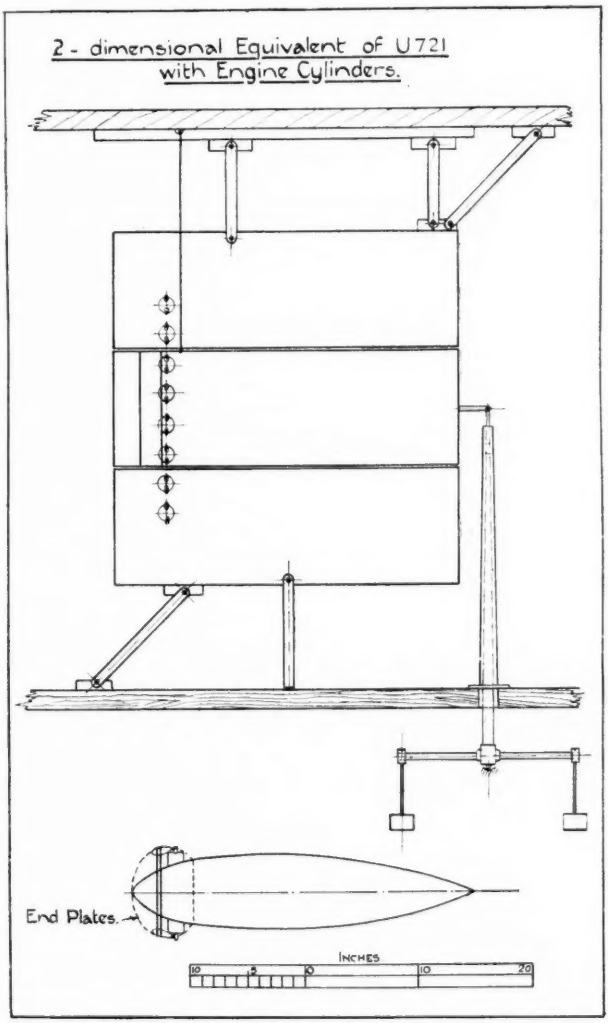


FIG. 1.

ring, from the aspect of not shielding the crankcase, and thereby lowering the general oil temperatures of the engine.

Personally, he was of the opinion that very little was still known about the technique of direct air cooling of aero engines, and that we had only just

" scratched the surface " of what was possible, and he wished to thank Mr. North for the very full survey of the possibilities of reducing drag of direct cooled engines by suitable cowling, which he thought should serve as a spur to the designers of air-cooled engines to endeavour so to scheme their engines as to take full advantage of low drag cowling.

Dr. H. C. H. Townend (F.R.Ae.S.): Referring to the rough rule given by Mr. North in the paper for estimating what the Townend Ring angle was likely to be to give the best results, he suggested that the question might be

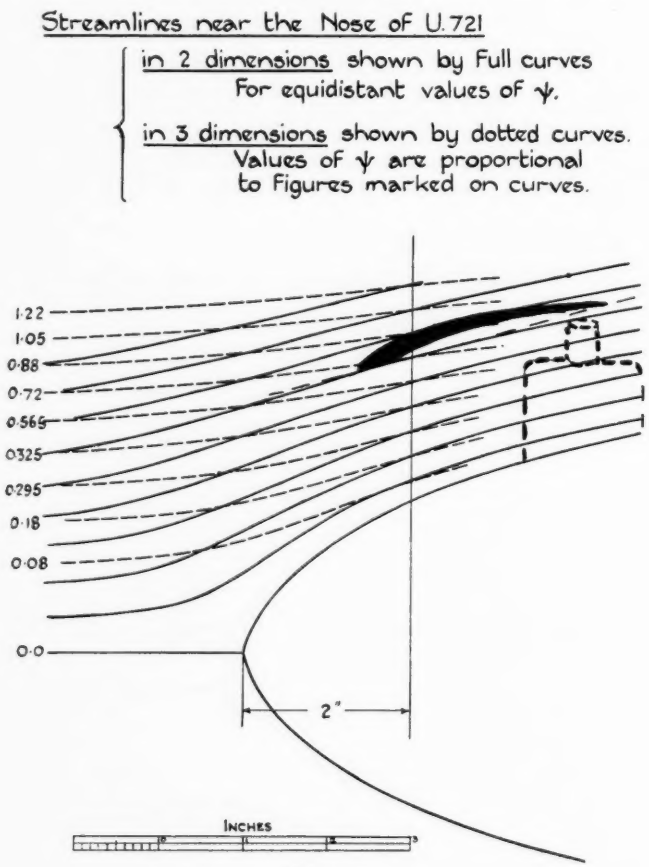


FIG. 2.

looked at from another point of view, which gave a result similar to that given by Mr. North's rule.

The first figure showed a model which he had tested in a wind tunnel at the National Physical Laboratory. The model was made in two dimensions, *i.e.*, the body was represented by a streamline form stretching across the tunnel somewhat similar to a thick symmetrical aerofoil, with a row of knobs above and below to represent the cylinders and two straight aerofoils to represent the ring.

The second figure indicated the air flow around the body in the absence of both the cylinders and the ring. The streamlines were calculated for the case of an elliptic cylinder (full lines) and an ellipsoid (dotted lines) in perfect fluid flow, and are known to agree closely with the actual flow pattern. The cylinders have been dotted in in the position which they would eventually occupy, and the ring was also shown in the position which gave minimum drag. He pointed out that in this position the section of the ring was lying with its no-lift line practically along the local streamlines, so that if the engine only were removed, the ring would not be expected to have much influence on the flow around the body. When the engine was introduced, however, it immediately put the ring up to a high lift coefficient by deflecting the air outwards and causing it to strike the ring section at a positive angle. This experiment suggests that if the streamlines were obtained, for example, by using smoke or a hot-wire shadowgraph, when the model was mounted in the wind tunnel without the engine on it, and with the nose faired, a good idea could be obtained of the angle at which the ring ought to be set when the engine was eventually put in its proper place.

With regard to the point mentioned in the paper that when the ring had a bulbous leading edge the overall drag was reduced, he asked if Mr. North had any idea as to the reason for that.

Discussing the statement that sometimes the effect of the ordinary crankcase cowling was to warm up the crankcase, Dr. Townend asked if it was not also a fact that it tended to make the cylinder heads somewhat cooler.

The bugbear of scale effect cropped up from time to time. It was stated in the paper that the drag of a Townend Ring cowled engine at one-tenth scale was always very considerably higher than that given by the one-fifth scale models, and that this was mainly due apparently to scale effect on the drag of the engine itself. Commenting upon this, Dr. Townend said that some years ago Mr. Relf, at the National Physical Laboratory, had suggested that, as the cylinders of an aircraft in flight were working at a value of Reynolds number which was above the critical, where the drag coefficient of an infinitely long cylinder underwent a very considerable drop, possibly the same kind of thing might happen in the case of the stub cylinders of a radial engine in flight. It was not possible to test this point adequately at the time, but now that the compressed air tunnel was in operation, Dr. Townend hoped to be able to make tests in it on a scale model of an aeroplane body and engine, both with and without a ring. The great advantage of such a test, in the case of an engine, is that it is the only kind of model/full-scale comparison which eliminates the difficulty of constructing an accurate model of the engine. The main interest of the experiment would lie in the test without the ring, of course.

Mr. ERIK HOFMAN: He assured Mr. North that the information contained in the paper was welcomed and would be studied very carefully. He thought Mr. North had been rather hard on the N.A.C.A. cowling, particularly in his remarks as to the obvious advantages of the Townend Ring over the N.A.C.A. cowling. The difficulty about the latter interfering with gun-fire had been overcome in several cases by the slight readjustment of the position of the gun, and a large number of military planes had been built in the United States with N.A.C.A. cowls fitted, there being no interference with vision.

With regard to cooling, Mr. Hofman referred to some tests on similar installations (with supercharged and geared engine), the one having no ring cowl and no baffles, whilst the other had N.A.C.A. cowl and baffles. In the latter case there was a reduction of nearly 50°F. in the maximum cylinder head temperature and an increase of speed of 15 m.p.h., under conditions of constant power and r.p.m., constant fuel consumption and constant density altitude.

Mr. HOLLIS WILLIAMS (A.F.R.Ae.S.): There was one interesting point in the paper which rather revised his ideas of how rings and the N.A.C.A. cowling worked (in connection with the annulus behind the cowl). It was interesting to

see in full scale a physical phenomenon which one knew must be true, *i.e.*, that if a ring cowling were working properly, symptoms of vibration, windscreen chatter, and so on, would disappear, due to the laminar flow produced by the cowling; and differences in temperature in a machine could be noticed, due to the warm air from the engine clinging to the sides of the fuselage, and that was one of the best methods of telling whether a cowling was working properly. It had always seemed to him that to secure the peculiar phenomenon of laminar flow it was necessary to rely on the sluicing of the air from the back of the ring There was a high-velocity low-pressure air stream ejected from the back of the ring, and that tended to pack the air down on to the body and produce the laminar flow.

It had been stated by Mr. North that in tests carried out in America, where the slots had been filled up behind the N.A.C.A. cowling, the drag was reduced. That upset the ideas which he (Mr. Hollis Williams) had had; it meant that the war-time rotary engine cowlings were as good as anything now produced, and he was not sure that this was so, as, in his opinion, the slot was necessary to produce the laminar flow.

Dr. MICHAEL WATTER (*contributed*): Speaking from personal experience and knowledge of difficulties encountered in many instances of fitting Townend Rings and N.A.C.A. cowls on aircraft, he was sure he was expressing the feelings of American designers by complimenting Mr. North on the valuable information contained in his paper.

There are a few points, however, which he desired to raise in connection with this paper and which, while being an expression of his individual opinion, he hoped would prove of interest to other designers.

Discussing " ring cowlings generally," Mr. North makes a statement of the supposedly basic difference existing between the Townend Ring and N.A.C.A. cowling. He felt that this difference is more a matter of definitions than any basic difference of principle, since the action of both of these cowlings is based on the idea of " suppressions of the breakaway of flow behind the body by the downwash from an annular aerofoil "—which in the case of the Townend Ring is achieved with greater mechanical simplicity and wider flexibility of adaptation for various installations. This radial restriction of airflow characteristic of both types of cowlings still leaves present the inter-cylinder interferences, with its resultant drag and incomplete cooling. It had been his—and he believed general experience in the United States—that in case of higher power, and particularly supercharged engines, it is necessary for proper cooling to use inter-cylinder baffles with both Townend Ring and N.A.C.A. cowling alike. With the use of the baffles the advantages of the Townend Ring are greatly reduced, since, while not imposing the same restriction on body form as is the case with the N.A.C.A. cowl, the field of fire for fixed guns, or rather the forward target visibility, is affected to the same extent in both cases.

As regards the increase of maximum speed, he was in accord with Mr. North's statement to the effect that Townend Ring and N.A.C.A. cowling, when properly fitted to a basically well streamlined body, give about the same increase in performance. The word performance is used here with reservation, since his personal experience did not indicate any particular gain in climbing or gliding ability, the effect of ring cowls being apparently restricted to high speed conditions of flight. It would be interesting to hear about this fact from Mr. North, whose broad experience with Townend Rings entitles him to speak with authority on this subject. It is the writer's opinion, however, that the very principle of ring cowls precludes any possible expectation of great gains in climb, precisely because of the radial restriction of flow effective for a definite range of angles beyond which occurs partial stalling of the circular aerofoil, with its resultant increase in drag.

In connection with this, he desired to mention his recent experiments with a new type of cowl which he called the " tunnel " type, and which differed from ring cowls because the restriction of flow is complete radially and laterally (in reference to individual cylinders) as well.

In the case of the tunnel cowl the engine is completely enclosed within the nose of a streamline shape forming one continuous whole of the body or nacelle proper. The cooling air enters through openings in front of each cylinder and is guided round the cylinder by means of individual tunnels, the restriction being complete in three directions. The distance between the walls of the tunnel widens to its maximum at the cylinder, and then converges to terminate in a point, the walls and side cut-out forming a triangular opening for exhausting the cooling air. This tunnel restriction causes the airflow to be directed round the rear of the cylinder head, and to be subsequently expelled by virtue of the higher velocity created in the tunnel, without the need of additional baffles.

Cooling of the crankcase is by conventional openings in the nose-cowl, which in this case forms part of the main cowl. The air thus admitted is expelled through a circular opening formed by the cowl shell and body.

Exhaust system consists of individual bayonet-type stacks located in the side air-outlet openings.

Exhaustive flight tests with a military two-seater biplane consistently indicated an increase in speed of about 12-14 miles per hour, with a definite gain in climbing and gliding ability. The original maximum speed of the aeroplane was 140 m.p.h. The gain in performance attained in this case indicates a decided aerodynamic superiority of the tunnel cowl. There was an increase of from 10 to 13 degrees in oil temperature, measured (because of the available installation) at the oil outlet opening. Up to the date of this writing the installation was operated over 35 hours with a number of full throttle flights lasting 40 minutes each, climbs over 18,000 feet, and normal flying at sea level with outside air temperature of 40°C. The oil consumption was not increased, no noises have been detected in rocker arms, and the engine performance is normal. To determine accurately the cooling of the engine a set of thermocouples will be installed at an early date for more exhaustive tests.

It is his opinion that the increased efficiency and better cooling characteristics of the tunnel cowl are due to the following facts:—

(1) The portion of the airflow not utilised to cool the engine is guided over an uninterrupted smooth streamline form of the portion of the cowl not containing cylinder openings.
(2) Cylinder interference is absent.
(3) Cylinder resistance is reduced.
(4) Cooling air is guided completely round the cylinder barrel.
(5) Better cooling efficiency is obtained because of lower velocity of airflow at the cylinder barrel.
(6) Better climbing and gliding ability is obtained, since the efficiency of the installation is not due to the aerofoil action of the cowl.

He believed the mention of his invention was justified here, because of Mr. North's broad treatment of the important subject of engine cowlings and also on account of the results obtained in tests which, although limited in number, definitely indicate interesting possibilities of this new method of cowling air-cooled engines.

Reply to Discussion

I think that some little difficulty necessarily arises from the fact that the term N.A.C.A. cowling has been loosely used, and, unlike Townend's device, it has not been defined in accordance with the requirements of the patent laws.

In order to try and clarify the situation, I have quoted from the reports of the N.A.C.A. their own statements as to what an N.A.C.A. cowling was, prior

to the publication of Mr. Townend's results. I think this is the fairest distinction which I could draw between the two devices. I certainly cannot see any justification for Mr. Fedden's suggestion that the existence of a forward component of air force on both cowlings is evidence that there is no engineering difference between them. The existence of this forward air component is inevitable from the situation of the cowlings in relation to the air stream and the body, and would, of course, exist in the N.A.C.A. cowling even though it had no rear aperture and no airflow.

It may perhaps be even more clearly brought home by referring to the Townend Ring on pusher installations—a point already raised by Mr. Radcliffe. From such little experimental evidence as we have, the drag reduction on a pusher installation with a five-cylinder engine has been shown to be 40 per cent., and the resultant force on the cowling is down-wind in this case and not up-wind.

My authority for the statement that efforts to use the N.A.C.A. type cowling on geared engines have been disappointing, and with the geared supercharged engines generally unsatisfactory, particularly in this country, was the Bristol Aeroplane Company (Reference 9). It must be remembered in the case of the Douglas the gear ratio is 3 : 2, as against 2 : 1 commonly used in this country, and that the engines are moderately supercharged. The statement that it would be impossible to cool the engine without a N.A.C.A. cowling, presumably refers to the necessity for some baffling system to ensure the cooling of the rear of the cylinders. The machine also operates at a very high speed, being loaded at nearly 19 lbs./sq. ft. The test on the Douglas of taking-off on one engine to which Mr. Fedden refers, was a very fine demonstration of the capabilities of the machine. It would be as well, however, to point out that in the test the one engine was only shut down after the machine had already run 1,000 feet.

I should like to hear Mr. Fedden's opinion as to the influence of the use of 87 octane fuel on the cooling problem.

I am doubtful whether, in fact, American controllable pitch airscrews have a worse effect on the cooling of the engine than the bulky centres of the wooden airscrews commonly used here on geared engines, particularly when it is remembered that, under critical conditions, the inner part of the blade may often be stalled.

The question of inter-cylinder baffles, the great effect of fuselage shape, "induced" cooling and total head measurements in front of and behind the engine, must all be considered together. We cannot consider the differences in total head as having any significance in relation to velocity, and consequently cooling, except where this head is referred to a particular baffling system inside the cowl; in other words, for a given difference of potential between the inlet and outlet of the cowling there must be a particular hydraulic resistance.

In the case of the Townend Ring, we have a large free airflow through the cowling, and the difference in total head will not be large. The cylinder baffles will not have a serious effect on drag unless they extend so far up the cylinder as to obstruct the circulation around the ring, and this is not necessary.

In the examples quoted by Mr. Fedden, for the N.A.C.A. cowling, the differential total head, viz., 4ins. water at 100 m.p.h., is only 40 per cent. of $\frac{1}{2}\rho V^2$. A general examination of the arrangement of N.A.C.A. cowlings does not suggest that a greater part of this differential head arises from the suction at the rear aperture, such suction, *i.e.*, reduction below the static pressure in the free airstream, can only arise in the case of streamline flow from contraction of the streamlines where they pass the aperture, or, alternatively, by discontinuity at the rear aperture giving rise to turbulence and consequently increase of drag. It is possible that both of these contribute in some small measure to produce the suction at the aperture, but it seems likely that the principal contribution to the differential head is the pressure at the front aperture, and of course a

very complete restriction by the baffling system. In the second case to which he refers, where change of body shape has made a big change in the differential head, it would appear to me that the body shape of the machine with the lower differential head was of such a nature as to give rise to considerable expansion of the streamlines at the rear aperture. This, if correct, would of course account for the loss of head. The Townend Ring, with its free-flowing air stream, should therefore be less sensitive to changes of body shape, though the importance of the shape of the body in the immediate region of the ring requires to be emphasised.

On the subject of carburation, during the course of the experiments on the foreign single-seater, reports of trials were made with the air intake placed outside the Townend Ring, but satisfactory results were not obtained, although some improvement was found with abnormally large air intakes.

The Patent Specification 11315 of Bradshaw, to which Mr. Fedden refers, is of interest because it discloses the use of controllable flaps to create a pressure reduction behind the cylinders, which is the basis to the present schemes for control, both in this country and in America. We cannot say from Bradshaw's specification that his cowling is practically identical with the N.A.C.A. type, because he shows no body. The direction given to the outflowing air by the guide channels is also significant.

The interesting suggestions made by Mr. Townend with regard to methods of experiment will be very helpful. As a matter of fact, one does not find very much difficulty in hitting off these things in the wind tunnel now; it is much easier intuitively to know how to set about the job than to explain how to do it. I could give some figures with regard to the bulbous nose which would surprise and interest Mr. Townend. Some rings with chord angle zero were tested by themselves in free air. With the one-tenth scale polygonal ring, using the bulbous nose, the drag was 18.26lbs., and with the one-fifth scale ring it was 17.72lbs., showing practically no scale effect. When the bulbous nose was removed, the drag was 31 on the one-tenth scale and 22 on the one-fifth scale. So that there was increased drag when the bulbous nose was taken off, and a very large scale effect. But I cannot give an explanation; this is far more Mr. Townend's province than my own.

In reply to Mr. Hofman's remarks, I do not think that he will feel that I have been hard on the N.A.C.A. cowling if I say that, in accordance with definitions given in the paper, many Townend Rings in America are called N.A.C.A. cowlings. Very useful practical progress has been made in the effective cooling of engines in the United States, and it is to be hoped that full advantage will be taken in this country of these developments. The example which Mr. Hofman quoted as to the improvement in cooling obtained with the use of cowling and baffles can hardly be discussed in the absence of full particulars of the nature of the body behind the engine. It is easy to imagine cases in which the effect of airflow might be improved by the presence of cowling and baffles.

I assume that where Mr. Hollis Williams uses the term " laminar flow " he is referring to the distinction between streamline and turbulent flow in the general air stream surrounding the body, and not to laminar and turbulent flow in the boundary layer. As a matter of fact, in 1924, Chenet did propose to fit a funnel at the front of the streamline body, something after the style of a ring, in order to produce laminar flow in the boundary layer. This, of course, was with a streamline body with no projections. Test showed that, so far from reducing the drag of the body by altering the flow of the boundary layer, the presence of this ring on a plain streamline body gave rise to increase in resistance. The importance of the flow of air along the sides of the fuselage is in relation to the projections of the engine cylinders outside the streamline which tend to cause a divergence. The resulting airflow along the body is therefore rather evidence

that the ring has done its work, and not the mechanism by which it performs. Where the cowling is a streamline continuation of the body shape, the filling up of the slot can hardly make the airflow around the body conform less closely, unless there is a substantial discontinuity at the slot exit, which we have by definition already excluded. The war-time rotary cowlings were effective in so far as they conformed to the general streamline shape, and the air flow through the cowlings was not of such a nature as to cause a disturbance. None of these cowlings satisfied such requirements, as, if they had, no sufficient airflow would have taken place over the engine, and the engine could not have been cooled.

In answer to Mr. Radcliffe, the figure of 40 per cent. reduction on a pusher nacelle has already been quoted, and probably much better results could be obtained with a nine-cylinder engine and a careful study of the best form of nacelle shape.

The ring has the effect of correcting the divergent air stream which these cylinders tend to set up.

I am not aware of any experimental results on the effect on performance of pusher airscrews, but I am doubtful if there are any general grounds for expecting an abnormal increase in nett propulsive efficiency. Mr. Radcliffe's proposal for using a ring as a source of energy is ingenious, but it appears to me that the practical disadvantages and complications of the mechanism involved would make one hesitate in attempting to make use of this energy.

I do not find myself able to agree with Dr. Watter that the N.A.C.A. cowling, as defined in the paper, is characterised either by downwash or an annular aerofoil. There is, of course, a radial restriction of flow in the case of both types of cowling, as also in the case of the cowling which he describes.

As already pointed out, the type of baffle used in a Townend Ring is different from the baffle used with the N.A.C.A. cowling, and does not extend so far up the cylinder as to affect visibility.

Dr. Watter's cowling appears to me from his description, and from the account written by him in " Aero Digest," of January, 1934, to be very similar to Bradshaw's cowling of 1917 described in his British Patent Specification No. 130827. The conception is similar to that of the helmet cowling described in the paper, relying for the reduction of resistance on taking a very small amount of air from the general flow and feeding it at a greatly reduced velocity to the cylinders. The practicability of cowlings of this type depends very largely on the amount of cooling which the cylinders require. I do not think that adequate cooling would be obtained with geared and supercharged engines, but no doubt further evidence on this point will be forthcoming in due course.

The drawings and photographs of his cowling in the " Aero Digest " do not seem to me to suggest any improvement in aerodynamic efficiency over the types of cowlings described in my paper, other than any gain which may have resulted from the reduced quantity of air and consequently reduced cooling of the engine. Particularly, it does not seem to me that, with the guides which he illustrates, the air is guided completely round the back of the cylinder. I shall, however, certainly look forward with great interest to direct comparative tests of this device with properly applied Townend Rings. It is important to say that when Townend Rings are properly designed they do not stall over the important part of the flight range, *i.e.*, from climbing to top speed, and, provided they are properly so designed, there is no reason to believe that the effect on climb and glide is other than would be expected from the reduction in drag resulting from their use. A considerable number of installations of Townend Rings have been made by engineers who have read or seen general descriptions of Mr. Townend's device but who have not had the necessary knowledge and experience to apply the invention correctly. It is important, therefore, to see that in any comparisons which are made, installations representative of best practice are employed.

THE COWLING AND COOLING OF RADIAL AIR-COOLED AIRCRAFT ENGINES*

BY

REX B. BEISEL, A. LEWIS MacCLAIN and F. M. THOMAS

This paper presents the results of co-ordinated research by The Pratt and Whitney Aircraft Co. (engines), the Chance Vought Corp. (airplanes), and the U.A.T. Research Division, all subsidiaries of the United Aircraft and Transport Corp. These studies were directed toward improving the performance of airplanes through reducing the drag of radial air-cooled powerplant installations as nearly as possible to the minimum necessary for adequate cooling.

The studies were supported by a considerable amount of experimental data. Extensive wind-tunnel tests provided quantitative measurements of airflow and drag for many combinations of baffles and cowling, and throughout the whole work simultaneous flight-tests checked results and contributed to the final conclusions. The successive stages of baffle development, as well as the experiments with various sizes and shapes of cowling, are discussed. The optimum combination ultimately found is described in detail.

The results of the studies show that much can be done to improve the arrangements now in general use. The use of the best type of baffle developed during the study, together with cowling designed in accordance with limitations determined during the course of the research, showed marked improvement in both aerodynamic performance and cooling over those of conventional arrangements, as is evident from the data and discussion presented.

The paper also points out the desirability of controlled cooling to compensate for variations in temperature and operating conditions, comparable to the use of a retractable radiator. The development of an entirely new type of adjustable cowl which successfully accomplishes this important objective is explained. Finally, mention is made of a few of the more important changes in powerplant installation which are made desirable by the use of the new baffling and cowling system.

The trend of design in the modern airplane has been towards improved performance realised through external cleanness. It is apparent that the number of essential units comprising a modern airplane is nearly a minimum at the present stage of the art, and it appears also that the possibilities of further striking reductions in the drag of these units, due to change in form or shape either individually or in combination, are not great.

Other than through detail refinement, what can be done to further reduce parasite drag? Where, in the airplane, are we sacrificing performance through ineffective design or operation? What other drag items of the airplane can be studied and investigated with possibilities of improved efficiency? A careful study leads us to the powerplant and the drag introduced in properly cooling the engine. We know that the total power expended in cooling is greatly in excess of that actually required to take care of the skin friction resulting from passing

* This paper was presented at the 1934 Annual Meeting of the Society of Automotive Engineers, Detroit. Mr. Beisel is connected with the Chance Vought Corp; Mr. MacClain with The Pratt & Whitney Aircraft Co.; and Mr. Thomas with the Research Division of the United Aircraft & Transport Corp. Reprinted by kind permission of the Society of Automotive Engineers, and of the authors.

air over the cooling surfaces of the radiator or of the cylinder fins. It has been shown* that in an actual case the total power expended to cool an engine equipped with a Townend Ring was some ten times greater than that which would be used in the ideal case, where the only air resistance realised would be that of the air " wiping the heat " off the cooling-fin surface. Since, as pointed out, the engine spent " 16 per cent. of its power in keeping itself cool," it is quite clear that we have some real possibilities to work with in endeavouring to improve the efficiency of the cooling system and thereby realise a marked reduction in the parasite drag of the airplane.

The purpose of this paper is to discuss the results of the experimental work which has been carried on jointly on the problem of drag reduction and controlled cooling of radial air-cooled-engine installations in aircraft. The tests and experiments have been conducted over a period of more than two years and are still continuing. They cover the development of both engine baffles and engine cowling. The main objective was to obtain the greatest possible improvement in engine cooling and airplane performance by combining effectively the design of both baffles and cowling. In attacking the problem of improving the cooling of the radial-engine installation, it may be in order to point out in a general way two definite controlling factors which must be considered.

First, we must accept a definite air resistance to obtain engine cooling, irrespective of the arrangement used in realising this cooling. This, as previously stated, is the resistance which must result in " wiping off " a certain amount of heat from the cooling fins. It is predicated on the cooling phenomenon of removing heat from metal surfaces. In actual practice, the resistance resulting from the removal of this heat is considerably greater than that due alone to the skin friction over the fins. This increase results from change of path, interference, restrictions, and turbulence of the cooling airflow from the time it enters the front opening, passes the engine and is again directed to the outside airstream. It is quite apparent, however, that the nearer we approach this necessary minimum drag, through the method employed in directing the cooling air to pass over the fins and in leading this air away from the fins, the nearer we come to obtaining necessary cooling with the minimum loss in airplane performance.

Second, we must accept a certain air resistance due to the parasite drag resulting from forcing the engine through the air. This assumes, of course, the arrangement of the engine in the conventional airplane. The engine has a certain frontal area; the propeller is in a given location. The best we can do, even assuming no airflow for cooling, is to house the engine in the best flat-nosed streamline shape and accept the resulting parasite drag.

With these two basic facts in mind, it is apparent that the real problem ahead of us is so to combine the design of engine cowling and the method employed in directing and controlling the airflow over the fins as to result in adequate engine cooling and, at the same time, minimum airplane drag. In other words, our objective is to obtain a combined arrangement such that the power expended in circulating the cooling air approaches as nearly as possible the ideal minimum, and that the power expended in forcing the engine through the air approaches that of an ideal streamline shape enclosing the engine. Following are some of the items of design which must be considered:—

An opening must be provided in the nose of the outer engine cowling for entrance of cooling air. How large should the opening be? What is the best shape of the nose of the outer engine cowl? Should a crankcase cowl be provided? The cooling air must be directed to the cylinder cooling fins. If baffles are used, what size and shape will be most effective to give maximum

* See *Aircraft Engineering*, February, March and April, 1932: The Theory and Practice of Air Cooling, by D. R. Pye.

cooling with minimum drag? The air leaving the cooling fins must be carried away and directed back into the airstream. What shape of engine accessory or wrapper cowl will give the best flow-path? What is the best shape of the after portion of the outer engine cowl? How large an exit opening should be provided for the cooling air? How can this cooling air be combined with the outer airstream to result in minimum turbulence? The cooling requirements in a given installation vary with operating and with seasonal conditions. Can a means be devised to control the cooling to meet these variable conditions?

It readily can be appreciated that the cooling-drag problem, with its many possible combinations of variables, was difficult to attack in a logical sequence of tests. The experiments leading to the final conclusions covered a great many flight tests and an even greater number of wind-tunnel tests, in the process of which we learned something first about one combination and later about another. It was necessary to study each test as we varied the set-ups, in order, logically, or, in some cases as we found later, illogically to proceed with further testing. For this reason, the following discussion, rather than covering the time sequence in obtaining results with various combinations, covers the work done and final results obtained in the development of:—

(1) A system of cylinder baffling;
(2) Engine cowling suited to the baffle system;
(3) Controlled cooling by means of the adjustable cowl flap;
(4) Other items of powerplant installation incident to items (1), (2) and (3).

Cylinder Baffles.—Important work leading toward our new conception of baffling was done in June, 1931, in connection with flight tests of the original Pratt and Whitney Twin Wasp engine (two-row, 1,830 cu. in. displacement). The standard baffle in use at that time was the conventional V-type skirt-baffle developed for use on single-row engines. Obviously, the same baffles were not adaptable to the front row of cylinders. Further, in developing a new baffle system, the problem was made doubly difficult by the fact that the cooling of the front and rear banks was dependent one on the other. A solution had to be attained wherein the cooling of either row did not adversely affect the cooling of the other row.

Excerpts from these early reports show clearly the difficulties encountered and the gradual approach to the final solution, as follows:—

" These cowling and cooling tests on the Vought V-50 with two-row radial engine No. X-26 installed were made prior to the airplane performance-tests in an effort to secure satisfactory engine cooling together with as high a top speed as possible.

" With no ring cowl, the cooling of the engine was very satisfactory, both in level flight and in climb. In nearly all cases, the latter was the critical condition. (See Fig. 1.)

" The addition of the narrow ring cowl to this set-up increased the top speed by 12.5 m.p.h., but raised the engine temperatures to prohibitive values. Those of the front heads were increased by an average of 115 deg., front bases by 55 deg., rear heads by 73 deg., and rear bases by 24 deg. Fahr.

" These tests illustrate the object of all the succeeding experiments; namely, to provide a narrow ring or N.A.C.A.-type outer cowling, which would give this very appreciable increase in maximum speed and at the same time devise a means of getting permissible engine operating temperatures.

" With the nose and front inter-cylinder cowling removed, but with the ring cowl still in place, the change in temperatures was negligible. Speed-course runs made on Aug. 17, and Sept. 8, 1931, showed that the variation in top speed due to this change was less than the experimental error.

" For tests Nos. 14 and 15 the standard V-baffles on the rear bank were removed, leaving the narrow ring in place. As a result, the rear cylinders, both head and base, ran very much hotter, while the front cylinders were only slightly

cooler. Throughout these flight tests the V-baffles were found to be the only satisfactory means of cooling the rear bank. With them in place, the front bases were critical and it was with these front bases that most of the remaining experiments were concerned. At this point some tests of the airflow through and around the narrow ring cowl were made. With the engine turning up on the ground, a smoke canister was held about 6ft. in front of the propeller (as shown in Fig. 2). The smoke showed a decided tendency to build up in front

FIG. 1.
Pratt and Whitney Aircraft Co. "Twin Wasp" engine without ring cowl and baffles.

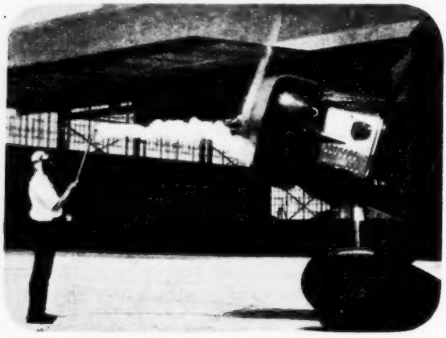


FIG. 2.
Checking with a smoke candle the airflow to a Pratt and Whitney Aircraft Co. "Twin Wasp" engine equipped with a ring cowl but without baffles.

of the ring cowl and then flow out around it. Apparently very little was passing through the engine. Back of the trailing edge of the ring cowl a very noticeable neck-in of the flow was apparent."

It is interesting to point out that this early concern, with respect to the lack of airflow through the engine, was misleading to say the least, since, in the final arrangement of baffles, the basic idea centred around limiting the volume of air passing the engine to that which passed over the cooling surfaces.

"In an attempt to cool the front bases with the narrow ring cowl in place, special curved baffles were designed and tried on cylinders Nos. 10 and 12. Two

positions of the baffles were tested; first, in close to the barrels, and then out about 1.5in. In both instances the temperatures were raised. Cooling was worse than with no baffles at all."

It should be stated at this point, as found in later tests, that it is quite impossible to interpret correctly the results of baffle tests on only a few cylinders as applied to the results that would have been obtained had these baffles been installed on all cylinders. In some cases the results are entirely contradictory. The reason for this will appear clear in a later part of this paper; but, had this been known during the early stages of development, a great deal of time loss and discouragement would have been avoided.

"Another type of baffle was tried in test No. 23. The baffles were triangular in shape and about 18in. long. They were fastened to the inner side of the ring cowl and extended from 1in. behind the leading edge of the ring cowl to 1in. behind the trailing edge, passing between the ears of the cylinders, both front and rear. They gave an average decrease of 13 deg. Fahr. in head temperatures, both front and rear, without affecting the bases. Since the head temperatures were already satisfactory, these baffles were not employed further. . . .

"It was found that an inner flange-cowl, as shown in Fig. 3, lowered the

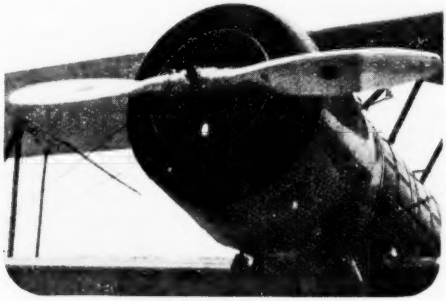


FIG. 3.
A full-length N.A.C.A. cowl and inner flange cowl.

front base-temperature an average of 16 deg. Fahr. while increasing the front head-temperatures only slightly. Rear head and base temperatures were a little lower with the flange cowl. In other words, the flange cowl considerably improved temperatures at the hottest points. A speed-course run of July 18, 1931, showed, moreover, that the flange cowl hardly affected the top speed."

Although this inner flange cowl gave promising results, it was later found possible to abandon it. It is mentioned here to show the extent of the ideas tried in an effort to solve the problem, and because it is allied with research work now in progress.

"When the N.A.C.A. cowl (full length, 41ins.) was tested, it gave temperatures which were higher than those with the narrow ring cowl. It also showed a gain in maximum speed of 3.2 m.p.h. over that with the narrow ring in the forward position."

Here again higher speeds could be realised, but only at the expense of increased cylinder temperatures. Later tests show, however, that high speeds and low temperatures were not necessarily incompatible.

"One more type of baffle was tried as a final attempt to cool the front bases by this means. These curved baffles No. 2 were simply flat scoops bolted to the inner side of the flangecowl. The trailing edges came to about the centre

line of the cylinders and were pulled in very close to the barrels. They were fitted only to cylinders Nos. 10 and 12. The improvement in cooling with these baffles was too slight to be worth while.

" Finally, on July 24, 1931, a cowling combination was found which was deemed sufficiently satisfactory for running airplane performance, but which still left much to be desired."

At this time, after continued testing from June 23 to July 24, 1931, a satisfactory baffle arrangement had not yet been devised. Upon completion of airplane performance testing, the baffle-test work was again resumed and continued into December, 1931. Very encouraging results were obtained, leading to the present conception of baffle design. Excerpts from the report on these tests are as follows:—

" Twenty-two thermocouples were installed on the heads and bases of all rear-bank cylinders and Nos. 4, 8, 10 and 12 of the front bank for temperature tests Nos. 1 to 49. For the succeeding runs additional thermocouples were installed on the heads and bases of cylinders Nos. 2, 6, and 12, making twenty-eight in all. All cylinder temperatures were measured with a potentiometer.

" Temperatures were measured in both level flight and climb and, unless otherwise noted, with the mixture control set at full rich for the sake of uniformity. The general procedure was to fly level at 2,000ft. with full throttle until the temperatures became steady; then to pull up into a climb at approximately best

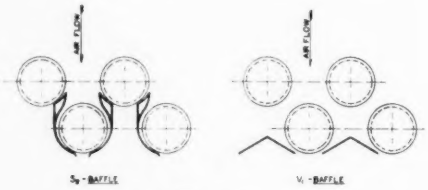


FIG. 4.
Comparison of S_2 with V_1 baffles.

climbing speed and continue until the temperatures began to drop. All temperature runs were made with the airplane at about 4,100lbs. gross weight and with the engine turning very close to its rated 2,000 r.p.m. at sea level.

" This series of cowling and cooling tests was begun on Oct. 14, 1931, immediately after the conclusion of the performance tests at two gross weights. All of the first twenty-one temperature tests were devoted to the determination of the best type of flange cowl to be used with the new design of *S* baffles (S_2) in the first instance, and with the *V* baffles (V_1) in the second. In addition, a comparison of the merits of the *S* and *V* baffles was sought. (See Fig. 4.)

" With all three types of flange cowl (Fig. 3), the S_2 baffles showed themselves definitely better for cooling than the V_1 baffles, except for the rear-bank heads; the temperatures of the latter were not critical. This improvement was not a matter of a few degrees, but an appreciable amount. The most marked improvement came in the front bases (average drop of 20 deg Fahr.), and the least in the rear bases (average drop of 1 deg. Fahr.). The front heads averaged 9 deg. cooler and the rear heads 24 deg. Fahr. hotter with the S_2 than with the V_1 baffles. . . .

" One other conclusion may be drawn from these two runs. Without any baffles front or rear, that is, with presumably the condition of maximum-volume flow of air through the engine, the front bases are still too hot, the highest temperature being 301 deg. Fahr. in full-rich climb. Thus it is evident that any scheme such as cutting openings in the noses of the V_1 baffles will not increase

the flow of air enough to attain satisfactory cooling. Apparently when outer cowling is used with this engine, baffles of some sort on the front cylinders are a necessity, regardless of the presence or absence of rear cylinder baffles. . . .

" Up to that time, no S_2 baffles had been installed between cylinders Nos. 7, 8 and 9, because of the oil sump. The sump apparently acted as a sort of baffle itself, for these cylinders seldom showed critical temperatures. The omission of the S_2 baffles between cylinders Nos. 2 and 3, 13 and 14, due to the presence of the front ignition-wire conduits, however, was more serious. These cylinders, particularly No. 3, very often gave maximum temperatures. For temperature tests Nos. 26 and 27, as well as all succeeding tests employing this type of baffle, S_2 baffles were installed between cylinders Nos. 2 and 3, 13 and 14, the lower parts being cut away to make room for the ignition conduits. In spite of the makeshift construction, the baffles lowered the base temperatures of these cylinders an average of about 5 deg. Fahr.

" The question arose as to just what was the quantitative effect on cylinder temperatures from adjusting the mixture control for best power in climb. For this reason three climbs were made in succession during the same flight with the conditions for all three identical except the mixture control. The first climb was made full rich, the second with a moderate use of the mixture, and the third at best power mixture. The results indicate that the change in mixture from full rich to best power in climb raises the head temperatures about 45 deg. and the flange temperatures about 15 deg. Fahr. As might be expected, the moderate use of the mixture gave increases somewhat less than these. . . .

" In order to determine the net beneficial effect from the best inner cowling and baffling combination thus far found, that is, straight-nose flange-cowl and S_2 baffles, *X*-26 was flown with no inner cowling. The improvement in cooling (due to the flange cowl and S_2 baffles) amounted to approximately 17 deg. in the head temperatures and 12 deg. Fahr. in the flange temperatures. These were average values. . . .

" With the conclusion of run No. 47 no further attempt was made to develop the flange cowl. There is no doubt that it improved the cooling of the flanges to a certain extent, but the gain was not sufficient to lower the temperatures to satisfactory limits. Added to that were the maintenance difficulties which such a cowl would present in service. The complete removal of the flange cowl required the removal of all push rods both front and rear, with the subsequent checking of all valve clearances.

" Up to this point every effort had been aimed at inducing a large volume of air to flow through the engine disc, while directing its flow as nearly as possible to the points needing cooling. Volume of air, however, was the essential objective. With the invention of what may be termed the plug type of baffle, as characterised by the head and contour baffles, *the objective became the definite limiting of the flow of air through the engine disc, together with an accurate control of the air which did flow, directing it to and over those parts of the engine which most required cooling.*"

This development proved to be the turning point in the battle. From this point on, the work was to a large extent a matter of detail refinement and improvement in baffle shape, size and arrangement. As indicated, however, in the preceding paragraphs, an unmeasurable amount of time and effort had been expended in arriving at what may appear to be an obvious conclusion.

Continuing with excerpts from the report :—

" The first use of this principle in flight came in tests Nos. 48 and 49 on Nov. 11, 1931. The head baffles employed were in two parts. The first (H_2) almost completely filled the spaces between the ears of both the front and rear cylinders, following closely the outline of the ears. The second part of the baffles (H_{2a}) supplemented the first by blocking, in a similar way, the openings

between the front and rear cylinder ears, that is, between two exhaust ears on one side and two intake ears on the other. (Figs. 5 and 6.)

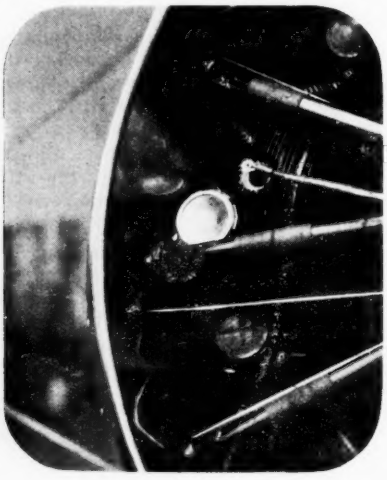


FIG. 5.
Engine equipped with head baffles (H_2) and contour baffles (C_1).

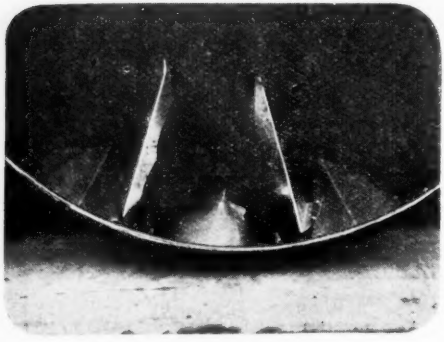


FIG. 6.
Attachment of head baffles (H_2) and contour baffles (C_1) to a ring cowl.

"These head baffles gave most gratifying results, lowering the head temperatures by an average of 56 deg. and the bases 9 deg. Fahr. The basis for comparison was a set-up similar except for the use of the straight-nose flange-cowl.

"Continuing the application of this principle, contour baffles (C_1) were designed which replaced the small baffles (H_{2a}) between the ears. They extended from the head baffles H_2 down to the cylinder flanges and followed the contours of the cylinders very closely, leaving only small openings next to the fins and, in

fact, touching them in many places. These baffles gave the most encouraging results thus far obtained. The full-rich tests first made with them were repeated, using a best-power adjustment of the mixture. In climb, the hottest rear flange was 303 deg., and the hottest front flange 291 deg. Fahr. This set-up gave 180.8 m.p.h. over the speed-course, indicating that the head and contour baffles have little if any tendency to reduce the top speed. Contour, head and V baffles were used in all of the succeeding tests."

The real advantage gained through closing off all air passages in the baffle system, other than those required for directing air to the cooling fins, is strikingly brought out by cooling tests on another installation. The baffles were of the new close-fitting type except that during manufacture and installation a few "leak holes" were still present. These were temporarily stuffed with steel wool and the temperatures of the heads were reduced an average of 17 deg. and of the bases 7 deg. Fahr.

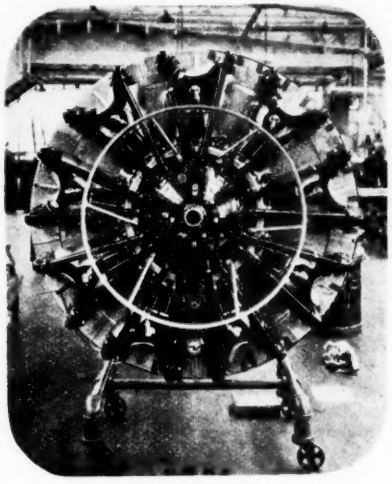


FIG. 7.

Front view of experimental pressure baffles on a "Wasp" engine, being the original baffles before trimming.

In order to identify the improved system of baffling where all the space under the cowl was tightly closed off, except the small amount required to admit and direct air to the fins, a new name was coined and henceforth these baffles were called "pressure baffles."

To date, the pressure baffles used in the experimental tests were made for the most part from aluminium sheet and the use of tin snips. They were secured in place, both to the engine and the N.A.C.A. cowl, with nuts and bolts and with little time for thought as to ready removability and maintenance. An order was released for a set of factory-built baffles, and considerable time and study were given to reduction of weight, simplification of design and ready accessibility to the engine. Careful attention was also paid to the reduction of leaks past the engine, except where actual cooling was required. In this new arrangement a sheet-metal diaphragm, to which the baffles were secured, was mounted on a circular hoop of steel tubing, the latter being attached to the engine. This arrangement obviated the necessity for attaching any baffles to the N.A.C.A.

cowl and also acted as a mounting for the cowl in addition to providing an air seal between the cowl and baffles.

Tests of this new baffle arrangement on the two-row engine, where special attention was paid to unnecessary leakage of air, as compared with baffles similar to the earlier set-up, showed an improvement in cooling as follows: Average reduction of head temperatures, 15 deg., and average reduction of base temperatures, 8 deg. Fahr.

Although we had arrived at the pressure-baffle idea, it was still necessary further to refine the design of the parts that directed the flow over the fins of the barrel and heads. Should they enclose almost all or only part of the cylinders? How large an inlet and exit opening should be provided? What should be the spacing between baffles and fin? In order to arrive at results which would

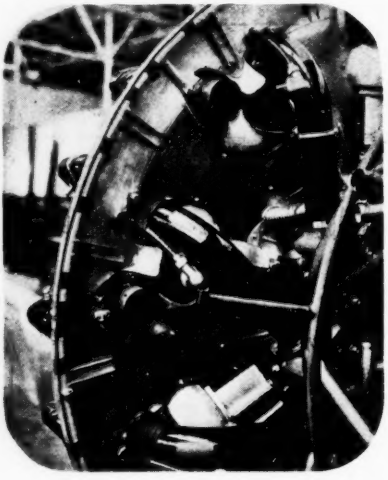


FIG. 8.

Rear view of experimental pressure baffles on a "Wasp" engine, being the original baffles before trimming.

be representative of the actual engine installation in the airplane and at the same time reduce the complexity of the problem as applied to the two-row installation, it was decided to carry on these tests on a single-row installation. Since the problem primarily involved the cooling of each individual cylinder, the results should be applicable to any cylinder arrangement.

To this end an experimental set of pressure baffles was designed and constructed for installation on a Wasp single-row engine. The attachment of the baffles was such as to permit ready removal and change of each part in arriving at the most effective set-up. Figs. 7 and 8 show the diaphragm and baffles on the original installation. The cylinders are almost completely enclosed; in fact, there was some doubt in our minds as to whether the engine could be safely flown with this arrangement; but, in an endeavour to at least bracket the results, this extreme condition was used initially, which permitted trimming the baffles on subsequent tests.

The tests, twenty-nine in number, consisted of complete temperature and speed runs. The baffles, head, barrel and ear, were trimmed separately, increasing first the front and then the rear openings; and, lastly, a new set was constructed

to check the most effective arrangement found. The tests took place during December, 1932, and January, 1933, on the Vought V-50 airplane. All runs were made at a 2,000ft. density-altitude, at a constant engine power of 550 b.h.p. and at a constant engine speed of 2,100 r.p.m. The method used in maintaining these constants is as outlined in a paper entitled "Commercial Flight Tests Improved by New Equipment and Methods," by A. L. MacClain and D. S. Hersey.*

As a result of these tests, the most effective cooling arrangement was found to be as follows:—

(1) The clearance space between baffles and fins should be as small as practical. A $\frac{1}{8}$-in. space corresponds very nearly to the best results obtained and prevents chafing between baffles and fins.

(2) The head and the barrel baffles should surround about 104 deg. of the head with a front opening of 228 deg. and a rear opening of 28 deg. The opening at the rear spark-plug should be increased accordingly.

(3) The ear baffle on the top of the heads between rocker boxes should cover all fins transversely and, in the fore-and-aft direction, begin at a point about $\frac{1}{2}$in. behind the transverse centre line, extending aft about $2\frac{1}{2}$ins. Allowance should be made to provide an exit opening for the fins around the ports; for example, the baffles between ports can extend somewhat farther aft.

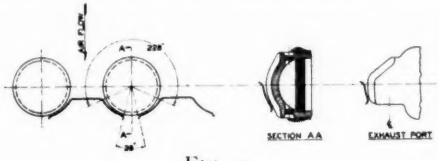


FIG. 9.

Typical arrangement and location of pressure baffles for a single-row engine.

Fig. 9 shows the arrangement of baffles, as described above. Tests conducted later show an improvement if the clearance space between baffles and fin is tapered; that is, if we provide an opening at the leading edge of the baffle of $\frac{1}{4}$in. to $\frac{3}{8}$in., gradually reduced to about $\frac{1}{8}$in. or less, at a point about two-thirds of the way aft from the leading edge of the baffle. The improved spacing only is shown in Fig. 9.

Perhaps the most surprising result of the tests is the size arrived at for the front opening, in that the baffles begin at a point *aft* of the transverse centre line. One apparent reason for this, however, is brought out in the results of airflow tests† on a finned cylinder where it is clearly shown that the breakdown of flow around the cylinder begins at a point slightly aft of the transverse centre line. The forward finned walls of the cylinder no doubt provide a natural flow path for the air with the necessary high surface-velocity.

It was also gratifying to find that changes from the poorest (initial arrangement) to the final most effective arrangement, although showing a material reduction in temperatures, showed no apparent loss in speed. These results are:—

	Average Head Temperatures, Deg. Fahr.	Average Base Temperatures, Deg. Fahr.	True Air-Speed, M.P.H.
First arrangement ...	484	270	178
Final arrangement ...	416	248	178
Temperature reduction ...	68	22	—

* See S.A.E. Journal, July, 1933, p. 245.

† See N.A.C.A. Technical Note No. 429, Aug. 1, 1932: Heat Dissipation from a Finned Cylinder at Different Fin-Plane to Airstream Angles.

With all baffles removed, but with the N.A.C.A. and other cowling in place, the average temperatures increased 62 deg. on the heads and 52 deg. Fahr. on the bases, and the true air-speed dropped to 167 m.p.h. All of the above temperatures have been corrected to a constant arbitrary strut temperature of 40 deg. Fahr. which represented the average of flight tests, by a method checked in many previous flights.

The information gained through the tests on this experimental set-up permitted us to proceed to the design of a practical set of pressure baffles for the single-row engine. The first set was bumped out and fitted by hand, emphasis being placed, however, on ease of manufacture in production and ready removal and replacement. Modifications were made in the engine design to accommodate attachment of the baffles. In order to assure effective operation in service before release for manufacture, these baffles were flight tested and certain improvements made.

The following description covers the results of flight tests on such a set of baffles designed for use and tested on a 3 : 2 geared 1600-D Hornet in the Vought V-50 airplane. All runs were made at a 3,000ft. density-altitude, at a constant engine power of 700 b.h.p., and at a constant engine speed of 2,150 r.p.m. The mixture control was set for best power at both level flight and climb. All engine temperatures were corrected to an arbitrary strut temperature of 60 deg. Fahr., because it was near the average for this series of tests.

Twenty-eight separate tests were conducted, but those of striking interest were on the engine as tested bare with no N.A.C.A. cowl or baffles, as tested with N.A.C.A. cowling only, and as tested with N.A.C.A. cowling and the best pressure-baffles in place. The following temperatures and speeds were obtained in level flight at best power :—

	Average Head Temperatures, Deg. Fahr.	Average Base Temperatures, Deg. Fahr.	True Air-Speed, M.P.H.
Bare engine only	420	254	175
Engine cowling only ...	479	268	190
Engine cowling and baffles	406	239	191

In climb at best power, the following results were obtained :—

	Average Head Temperatures, Deg. Fahr.	Average Base Temperatures, Deg. Fahr.	True Air-Speed, M.P.H.
Bare engine only	430	262	110
Engine cowling only ...	Too hot—could not climb		
Engine cowling and baffles	436	250	110

It has been generally understood that the bare engine alone will always cool better than with some type of speed cowling. Contrary to this belief, the engine, when equipped with the N.A.C.A. cowl and pressure baffles, showed that the speed was not only increased 15 m.p.h., but the cylinder temperatures were also reduced an average of 14 deg. Fahr. In the climb condition, the temperature change also slightly favours the pressure baffles. With pressure baffles omitted under the N.A.C.A. cowl, the temperatures in level flight were 73 deg. and 29 deg. Fahr. higher for heads and bases respectively, as compared with the pressure baffles in place, and in climb the omission of the baffles gave temperatures too high to continue testing.

With the N.A.C.A. cowling alone, the speed was 1 m.p.h. lower than with the pressure baffles included. The N.A.C.A. cowl used on these tests was, as shown by later data, better suited for use without pressure baffles. Had this cowl been designed to embody an arrangement best suited to the use of pressure baffles, the high speed with the latter, based on data available, would have been increased about 2 m.p.h. Had the cowl at the same time been changed to reduce the velocity of flow through the pressure baffles, thereby raising the cylinder temperatures to agree with the higher temperatures obtained without

baffles, the resultant reduction in drag probably would have raised the high speed 5 to 6 m.p.h., thereby increasing the top speed of the pressure baffle installation from 191 to 198 m.p.h.

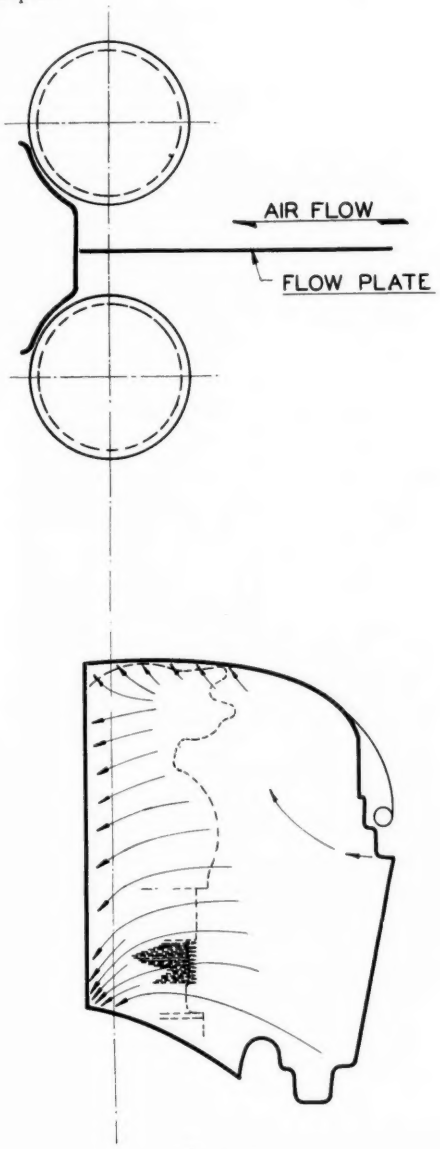


FIG. 10.

Flow paths of air entering pressure baffles. The high flow indicated in the lower left corner is due to leakage through a hole in the baffle.

On three other installations, where speed comparisons were obtained between the conventional *V* baffle and the new pressure baffle installation, both equipped with an N.A.C.A. cowl of good design, the increase in speed with the pressure baffles was in all cases about 4 per cent. Emphasis should be placed, however, on the fact that this increase in speed is not due to the use of pressure baffles in themselves, but rather to the latent possibilities of drag reduction made available through the use of pressure baffles. In other words, the actual drag-reduction results from the cumulative effect of being able to cool with lower volumes of air, and hence being able to design more efficient cowls.

Interesting results were obtained, in conjunction with these tests, in obtaining flow paths of the air as it passed from the front cowl opening back to the baffles. Fig. 10 shows one of these patterns, which were obtained by painting flat aluminium plates with lampblack and kerosene immediately before the flight test. The flow lines show that the path of the cooling air is fairly smooth and that its velocity is very low, except at the rear edge of the plate where the air enters the spaces between fins. The indicated high velocity at the bottom point of the baffle is due to a leakage hole between the baffle and the crankcase.

Figs. 11 to 14 show some of the latest developments in production types of pressure baffles for use on single-row and two-row engines. These are now

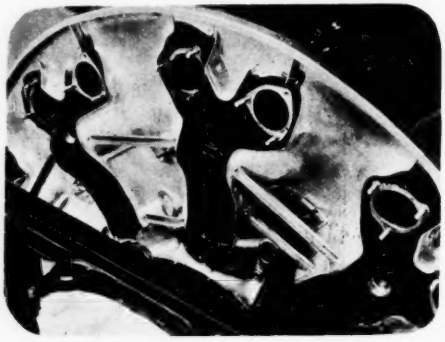


FIG. 11.

Rear view of late-type pressure baffles installed on a single-row radial engine.

furnished as standard equipment on all two-row models and as optional equipment on many of the single-row engines manufactured by The Pratt and Whitney Aircraft Co.

Engine Cowling

During the progress of the development of the pressure baffles, it was clearly indicated that the type of cowling used had a marked influence on both engine cooling and airplane performance. Before proceeding with the discussion of the cowling development itself, let us consider for a moment the status of the problem at this point in its development. From the data available on the results of the hundreds of tests conducted on the many variations and combinations of pressure baffles, we are in a fair position to believe that we have reached a point of efficiency where a marked improvement through basic changes in the baffle design will be difficult. This statement is based on the fact that the baffles as finally developed are basically sound in principle. They block off all airflow passing the engine except that used for cooling. They direct this air over the hot fin-surfaces.

The clearance between fin and baffle, the length of the baffle, the size of the front opening, the size of the rear opening and the shape of the leading and trailing edges of the baffles have all been explored and the most effective arrangement finally adopted. This involved no compromise between drag and cooling, since, after arriving at a certain point in the baffle design, further changes to

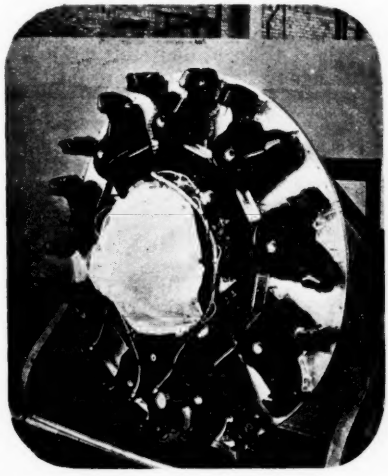


FIG. 12.

Front view of late-type pressure baffles installed on a single-row radial engine.

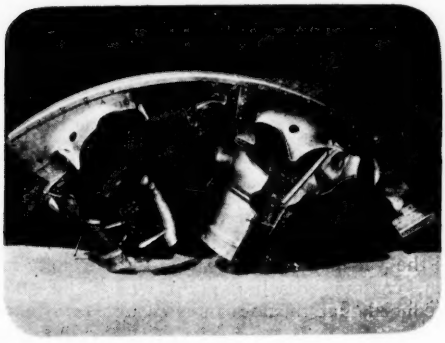


FIG. 13.

Rear view of late-type pressure baffles for use on a two-row engine.

improve cooling resulted in no measurable change in performance. It is, of course, obvious that a certain velocity of airflow over the fins is required to cool them properly, but the function of the baffles is not to supply an airflow to themselves, but rather to use the flow supplied as effectively as possible in cooling the engine. In other words, the baffles are entirely ineffective with no airflow

but, for any *given* velocity of flow through them, regardless of how supplied, either by the forward motion of the airplane or by means of a pressure blower in front or a suction fan in the rear of the baffles, their effectiveness in cooling the cylinders still remains the same.

Further, and again regardless of how the airflow is supplied, the only power loss from the baffles themselves is in the drag that is produced by the air at this same velocity as it passes through the baffles and over the fins. It is possible and even probable that further developments in air-cooling technique will discover minor advantages to be gained from leading the air to and from the pressure baffles in specially shaped ducts; but these refinements are subsidiary to the basic principle already established.

The problem now is to supply an airflow to the baffles such that the velocity of flow over the fins is just sufficient to keep the cylinder temperatures within

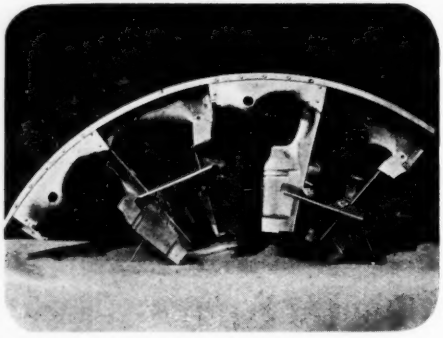


FIG. 14.

Front view of late-type pressure baffles for use on a two-row engine.

limiting value and at the same time to devise a means such that, in the process of supplying this airflow, the resulting loss in airplane performance becomes a minimum.

Whether we use a blower or depend entirely on the forward speed of the airplane, the principle of operation is essentially the same; that is, we direct the outside airstream to the front face of the engine, pass it over the fins, and exhaust it into the outer airstream. There are various efficient ways, through cowl design, of inducing a much higher air velocity through the fins than that induced through a normal cowl by the forward velocity of the airplane. However, as we continue to increase the velocity over the fins to abnormally high values through extreme cowl design, we may reach a point where the efficiency of the cowl arrangement is so reduced that the loss in airplane performance is excessive.

It appears that a blower system may be advantageously utilised to act as a booster in obtaining the required air velocity over the fins in the event of the velocity of the airplane being so low that only an efficient cowling arrangement will provide this required fin velocity. Nevertheless, even though we provide a blower to act as an auxiliary, it seems apparent that it can still be used most effectively in conjunction with an efficient cowling system designed primarily to make use only of the forward velocity of the airplane.

The purpose of the following discussion is to outline the results of the work that has been carried on in arriving at what is considered to be an efficient type of cowling arrangement. Basically, it consists of the application of the N.A.C.A.

cowl to pressure-baffle cooling. The results are from full-scale tests in connection with the baffle development and from wind-tunnel tests on a model.

Fig. 15 shows a diagram of a typical arrangement. The part of the N.A.C.A. cowl forward of the baffle diaphragm is called the " nose," the part aft of the baffle diaphragm is called the "skirt," the air-exit opening is called the " gill," and the rear cowl adjacent to the gill is called the " shoulder," the latter normally being a part of the engine-compartment cowl. It may be noted that this cowl

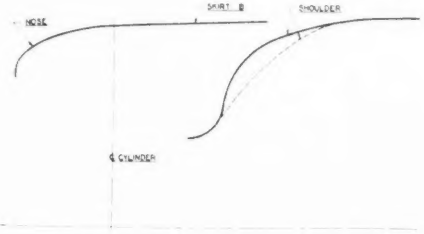


FIG. 15.
Typical engine-cowling arrangement.

runs down to the engine mounting-ring and fits tightly around the crankcase. This was originally considered desirable in providing a smooth airflow to the gill, but was later found necessary to keep the rear engine compartment cool.

Due to the time and expense that would be required to develop an efficient cowl from flight testing alone, a one-quarter size (13ins. diameter) wind-tunnel model was constructed, and over two hundred separate combinations of nose, skirt and shoulder were tested. A special feature was incorporated in the model to permit application of the results to full-scale installations. No attempt was made to obtain data that could be used in predicting quantitative changes in performance. The purpose of the tests was to obtain comparative effects only.

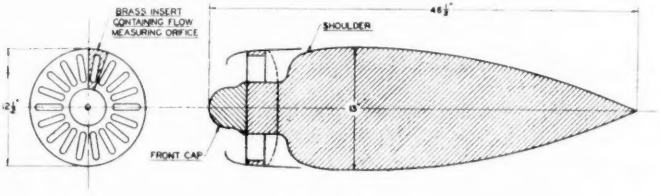


FIG. 16.
General arrangement of quarter-size wind tunnel apparatus.

Fig. 16 shows sectional views of the model. The shoulder, baffle, nose-section and skirt parts are detachable so that they may be replaced by different test pieces. The unique feature of the apparatus is the baffle which takes the place of the engine. It is made of wood and is 2ins. thick. Eighteen radial slots open through it, one of which is cut in a brass insert. This slot has a small static-pressure orifice in its side. A screen is used behind the baffle to diffuse the jets of air.

Flight tests and previous wind-tunnel tests had shown that the drag of a cowling was intimately connected with the amount of air passing through the engine. In the case of a cowl which was well designed for a certain condition, increases in flow always caused increases in drag. As was subsequently found out, increases in overall drag due to increases in flow for the same shape of test

pieces were in many cases larger than differences in drag due to differences in the shapes of the test pieces at the same flow. The importance of regulating or at least of measuring flow in comparative cowl tests was thus evident.

The apparatus used fulfilled this requirement. The static pressure in the side of the brass insert served as a means of measuring the velocity of air through the slots. This calculated velocity was checked with a separate calibrating apparatus which measured the volume of flow through the baffle at various orifice-pressure readings.

The quantity of air flowing was a function of the number and size of the baffle openings. In order to obtain results comparable to full-scale conditions, it was advisable to have the velocity of the air leaving the gill in full-scale relation to the free-air velocity. Tests on a complete engine made in the laboratories of the engine company gave data on the amount of air which was passing through the engine when adequate cooling was obtained with close baffles. This quantity, corrected by scale factors for model size and free-air speed, enabled us to run the tests at proper air quantities. The drag of each cowling arrangement was thus obtained as a direct function of the amount of cooling air which it permitted to pass through the baffle.

All of the comparisons among cowls are made at one tunnel-air speed and with one baffle opening. The latter requirement is parallel to flight testing comparative cowls with one set of pressure baffles. It is an important one, because it is essential that the changes in measured drags and flows be caused only by changes in cowlings. A change in baffle would obviously cause a difference in flow. It would likewise cause a difference in drag which would not be representative of a particular cowl because part of the drag change would be due to changing the drag *coefficient* of the baffle. When one baffle only is used, however, any change in the drag of the air passing through the baffle is rightly chargeable to the cowling because it is a result solely of the change in air speed through the baffle caused by the cowl.

In the actual test work, we considered the possibility of cowls showing up differently when tested with different *baffle* arrangements, and to take care of this contingency we made a complete series of cowl comparisons with one baffle and tested the same comparative series with a different baffle, and then again with still a third. This was done by varying the number of opening holes in the wind-tunnel baffle. In each case we found that the relative merits of the cowls ranked in the same order with one baffle as they did with the other baffles. This indicated that cowl comparisons made with one baffle opening truly showed the relative merits of the cowls. This is an important point for flight-test work also, as has been found in our testing.

All of the wind-tunnel cowl-analysis is based on the conception of flow through the baffle as an indication of cooling capacity. While it is evident that there is a close connection between the two, it is of interest to discuss the matter briefly. It brings up a subject which is of vital importance to the aircraft industry, but upon which little work has been published. Within the last year a few pioneer papers on this question have appeared; perhaps the best general survey, with applications, is a series of articles* by D. R. Pye, previously referred to. This subject might be called "Air-Cooling Performance Calculation," and might be defined as relating airplane design and operation to the prediction of engine-cylinder temperatures by the application of existing information on aerodynamics and heat dissipation. The basic principles governing the flow of air through orifices like engine fins and baffles are already available, and there remains the problem of co-ordinating them with the existing knowledge of heat flow. This last is difficult because of the complexity of the applied theory. Nevertheless, certain general theorems may be employed to obtain useful information, bearing in mind that these are subject to a complex inter-relation of minor variables.

The following is an example: The classical equation of heat flow which was derived partly from dimensional reasoning may be rearranged and applied to engine-cylinder temperatures in the following equation:—

$$T = k + (k_1 \, b.h.p.^x)/(\rho^y V^z) \quad . \quad . \quad . \quad . \quad (1)$$

where T = cylinder temperature.

k = air temperature.

k_1 = a coefficient.

$b.h.p.$ = engine power.

ρ = density of air passing over the cooling surfaces.

V = velocity of air passing over the cooling surfaces.

The exponent z in equation (1) ranges from 1 down to much lower values, depending upon where the speed is measured in relation to the fin, the type of flow over the fin, and so forth. The exponents x and y may be taken to be 1 or slightly less. The coefficients k and k_1 depend on a number of things. One group of these relates to the proportion of heat dissipated through the fins and includes overall engine efficiency and heat dissipated through the oil and crankcase. Another group relates to the relation between the measured cylinder temperature and the mean temperature difference between the air and the cooling surface; this is subject to variations in types of fins and baffles, and distribution of heat throughout the engine, such as difference between head and base temperatures. The coefficients and exponents must be chosen carefully. We have used modifications of this equation to estimate *changes* in cylinder temperature due to changes in major variables. In some cases agreement with flight-test data on average cylinder temperatures was remarkably close and, in other cases, large discrepancies have occurred.

This subject is mentioned, not to present the results of research, but to stimulate further work by drawing attention to it and to indicate the influence of airflow through the baffle upon engine temperatures. The equation shows that, except for a factor involving air temperature, cylinder temperatures are inversely proportional to the speed of air through the baffle. We have already given reasons which necessitate running comparative cowl tests at one baffle opening. When this is done, the speed of the air through the baffle is determined only by the quantity of air flowing. Thus, everything else being equal, quantity of airflow through the baffle is an excellent measure of cylinder temperature.

By these methods a wind-tunnel apparatus was made available for obtaining comparative data on many cowl arrangements, cheaply, quickly and accurately.

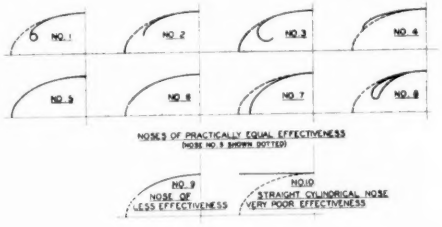


FIG. 17.

Cowl "nose"-shapes.

The first tests conducted were to determine a good shape of nose. Fig. 17 shows the nose shapes tested and the results of these tests. These noses were tested with a good skirt and shoulder combination and the conclusions drawn as to the proper shape should also apply to other skirt and shoulder combinations. Since the diameter of the engine, the diameter of the front air-inlet opening and the location of the propeller control the dimensions of the nose within narrow limits, the main variable is the contour or curvature of the nose. A comparison

of the test results shows quite definitely that the contour should be approximately elliptical with the leading edge tangent to a line normal to the thrust line, the trailing edge being tangent to the after skirt-line. This arrangement gave the best results irrespective of the relation between diameter of engine and diameter of front opening; and, conversely, very poor results were obtained with a sharp leading edge, that is, a non-tangent leading edge making a sharp angle with the normal to the thrust line.

Earlier flight tests on nose shapes checked the foregoing. In one case the original nose extended in toward the thrust line, but normal to it. By cutting off the nose at this point—that is, increasing the diameter of the front opening—the true ellipse was still retained and a marked reduction in engine temperature was realised with no reduction in airplane speed. Continued enlargement of the nose opening, which increased the sharpness of the angle of the leading edge, resulted in practically no reduction in engine temperatures, but was accompanied by an appreciable reduction in airplane speed. Making the nose angle still sharper caused some reduction in temperatures, but a very marked reduction in speed. The following tabulation shows some of the results of these flight tests:—

Opening, Sq. in.	Shape of Nose	Average Head Temperatures, Deg. Fahr.	Average Base Temperatures, Deg. Fahr.	Velocity, M.P.H.
240	Elliptical	429	264	185
450	Elliptical	391	256	185
650	Sharp entry	384	255	183
700	Very sharp entry ...	364	250	176

The function of the forward elliptical nose cowl is not only to provide a smooth flow-path for the air passing over the outer cowl, but also to act as a retainer for the inside air ahead of the baffles. The airflow in front of an engine with baffles, but without nose cowl, would be largely radial. This means that the total pressure of the air at the entrance to the baffles would be much less—and therefore so would the flow through the baffles—than the maximum obtainable free-air dynamic pressure. Measurements of the static pressure ahead of the baffles with good nose cowls, both in flight tests and in wind-tunnel model-tests, show that the static pressures obtained are from 85 to 95 per cent. of the free-air dynamic pressure. The 5 to 15 per cent. difference is due to the air velocity in the direction of the fins plus the losses due to the eddying and radial flow which occur even with good nose cowls.

Cowls with excessively large entrance areas are intermediate, in producing flow between good nose cowls and no nose cowls. Wind-tunnel tests of a straight cylindrical nose (Fig. 17) as compared with an elliptical nose, show definitely that the former had a materially higher drag, but at the same time permitted less airflow through the baffles. In fact, the drag with the cylindrical nose was much greater than with no nose at all, and the airflow with no nose was only very slightly less.

The cowl entrance-area can be varied within reasonable limits for a given engine without materially affecting performance. To an uncertain extent, the choice of nose diameter is influenced by the presence of the propeller, an effect not taken into account in the wind-tunnel tests. Although flight measurements with different designs of standard propellers have shown that there is little variation in the static pressure of the air in front of the baffles, it is logical to suppose that the portion of propeller near maximum engine diameter does furnish some increase in the cooling of the heads. Experience with many installations shows that best results are obtained when a larger entrance diameter is used for a two-row engine than for a single-row engine, which has a larger diameter for the same power. This is probably due to a propeller effect rather than to any question of allowing enough air to pass, because, in either case, the cowl entrance-area is much greater than the area of the passage through the baffles. In our

test work, satisfactory results were obtained when entrance diameter, as a percentage of engine diameters, were within the following ranges: Single-row engines, 65 to 75 per cent., and two-row engines, 75 to 85 per cent.

Raising the percentage above the maximum value for two-row engines has shown a reduction in top speed with little, if any, improvement in cooling, and lowering the percentage below the minimum value given for single-row engines has increased cylinder temperatures with no gain in top speed. It is probable that further increase in the diameter for single-row engines may be desirable. The opening used should be influenced to some extent by the speed of the airplane in climb and level flight, and for certain ground operating conditions it may be necessary to provide a still larger opening, at some sacrifice in performance, in order to realise sufficient airflow for cooling from the propeller alone.

The next step in determining the best shape of N.A.C.A. cowl was investigation of the contour of the "skirt." This problem is made difficult by the fact that the size of the fuselage or nacelle aft of the cowl may be larger or smaller in diameter than the diameter of the engine. Both wind-tunnel and full-scale tests show fairly definitely, however, that least drag is obtained by locating the skirt contour on a faired line extending back to the nacelle or fuselage, as shown in Fig. 18. With a large engine and small fuselage diameter it is difficult

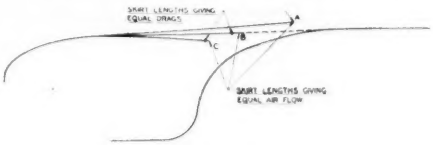


FIG. 18.

Skirt contours.

The poorest skirt, becoming worse as the angle is increased is shown at A, and the best skirt contour, fairing into the fuselage, at B. The skirt shown as C is slightly inferior to that shown as B.

to lay in a faired line, but a line extending aft from the skirt should bear into the fuselage line and not extend outside of it. In other words, a small fuselage requires a converging skirt, whereas a large fuselage requires a diverging skirt.

The wind-tunnel tests of a number of skirt combinations having a variation in angle comparable to those shown in Fig. 18 show a maximum variation in drag, for the same airflow through the baffles, of only 5 to 10 per cent. This figure also shows the relative lengths of the three skirts to give in one case equal flows and in the other case equal drags. As in the case of the nose shape, small changes in the angle of the skirt will not materially affect the drag at the same airflow, provided the angle of the skirt does not diverge beyond the faired line extending back to the fuselage. The matter of limiting our conclusions with the remark "at the same airflow," and the means employed in comparing the test results at one airflow, will be made clear later on in the paper.

Intermediate between the design of skirt and shoulder is a question of refined design which may later be found advisable to consider. Should the exit gill of the cowl ever be radially unsymmetrical? On the average, cylinder temperatures in climb are higher for the top cylinders than for the bottom. This, coupled with the fact that many bodies behind the engines are unsymmetrical, indicate that it should. For instance, later test work probably will show that it is best to have a larger exit gap at the top of the gill and at such other places (like the wing of current twin-engined monoplanes) as the air is impeded by obstructions. Still other expedients may be desirable, such as curving the skirt and shoulder in a manner to lead the flow smoothly and evenly around the obstructions.

We have covered the test work in conjunction with the determination of the best contour, nose and skirt, for the N.A.C.A. cowl, and the next step is the determination of an efficient arrangement or shape of shoulder. The real function of the shoulder is to provide a flow path for the air leaving the baffles such that, in combining with the external flow over the skirt, the resulting drag is minimum. The only systematic test data available are on the wind-tunnel model; but the general trends shown in various flight tests, and the agreement obtained between flight and model tests on other details of the cowling, indicate that the conclusions arrived at are valid.

The results of the wind-tunnel tests show that the critical point in the shape of the shoulder is near the gill opening. This appears to be entirely reasonable, since it is at this point that the air velocity is materially increased as compared with the velocity in back of the baffles and, further, the curvature of the shoulder at this point, combined with the curvature of the skirt, control the direction of flow of the air as it combines with the external flow. Fig. 15 shows two shoulder arrangements. The difference in drag at the same low flows is negligible, but the shoulder having the easy curvature shows some slight reduction in drag at high airflows. Fig. 19 shows a series of shoulder arrangements similar to those used on certain installations. The test results, as indicated in Fig. 19, again

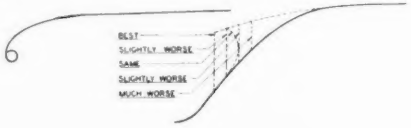


FIG. 19.

A series of sharp shoulders.

All of these shoulders were less efficient than the continuously smooth shoulders.

point out that any obstruction in the region of the gill should be as far forward as possible and that the direction of flow through the gill should lead the air smoothly into the external flow.

We wish to emphasise at this point that the designs for a fixed cowl recommended in the original researches by the National Advisory Committee for Aeronautics come remarkably close to those which we conclude to be best for use with pressure baffles.

Controlled Cooling

In the preceding discussion on cowling, all comparisons of the model results have been made on the relative drag of the various arrangements at a given airflow; that is, for comparative purposes at a given cooling effectiveness, at one air speed. No direct information has as yet been presented to show ways of varying the cooling by modifications of the cowling. With a given engine and a given cowl arrangement in a fast and in a slow airplane, the former will show lower cylinder temperatures. How can the cowl be modified to improve the cooling of the slower airplane; that is, increase the velocity of flow through the baffles? The same question may be asked about two engines identical except for power rating.

As pointed out in previous paragraphs, minor changes in a good cowl arrangement may be made without increasing the drag, but the improvement in cooling can hardly be expected to be large. However, it is readily possible to increase the velocity of flow through the baffles by an appreciable amount if we

also accept appreciable increases in drag. The first information on the foregoing was obtained through flight tests; and the means employed in increasing the flow through the baffles, thereby reducing the temperatures, was by trimming or reducing the length of the skirt. As the skirt was successively shortened, the cooling improved and the speed dropped off. The average change was of the order of 12 deg. and 6 deg. Fahr. drop in head and base temperatures, respectively, for 1 mile loss in speed, except that, as the skirt was successively trimmed, the rate of change in speed became greater for a given change in temperature. In fact, with an originally small gill opening, trimming the skirt 1in. or 2ins. can be expected to improve the cooling with no noticeable change in speed.

As our work progressed, it became desirable to obtain more data on this subject. Accordingly, several skirts were tested in the wind tunnel at various skirt lengths. Fig. 20 shows curves of model drag plotted against airflow for

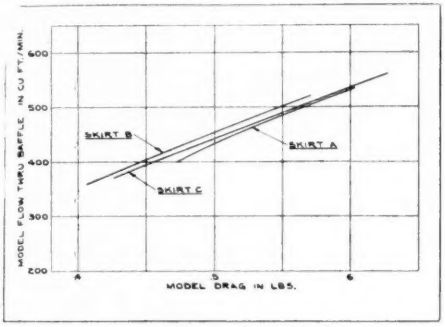


FIG. 20.

Curves showing drag and airflow for varying lengths of skirts A, B and C.

the skirts shown in Fig. 18. The curves shown were obtained using one tunnel air speed, one nose, one shoulder and one baffle. The flow was increased in each case only by cutting off or shortening the skirts. Polar curves of this sort for two skirts show directly their comparative merits. When one skirt lies to the right of another skirt, it is less efficient because the drag for a given flow is greater than for the other skirt. Sometimes the curves join each other at low flows, indicating that there would be little to choose between the two skirts if they were used on engines that cooled easily or on very fast airplanes. The skirt curves rarely crossed each other.

This method of changing flow was used in determining the relative merit of nose and shoulder shapes; for example, each skirt length of the three skirts was tested with each change in nose or with each change in shoulder. Plotting these results provided a means of comparing noses and of comparing shoulders at any given airflow. In all cases, these curves indicated consistently that the relative merits of the shoulders or of the noses remained the same when tested with any reasonable combination.

The curves of Fig. 20 show that the difference in drag between the skirts is quite small and that the relative merits of the three skirts is unchanged as their lengths are decreased. They also show that the effect of flow upon drag predominates. Tests of other cut-off skirts give similar results. Fig. 21 shows a typical curve of airflow plotted against model drag over the full range for one cowl arrangement having different skirt lengths. This curve is representative of a number that were run.

The general effect of shortening the skirt is quite evident from the curve. When the skirt is so long as to permit no air to pass, its drag is still above that of a true streamline body. This fact was established separately. As the skirt is cut off, the airflow passing through the baffle increases rapidly with only slight change in drag. Other skirt-shoulder combinations may yield small decreases in drag for small initial increases in flow. As cutting off the skirt is continued, the flow still increases but the payment in drag has increased still more. The most flow is obtained when there is no skirt at all; in other words, when the ring cowling consists merely of a nose section whose after edge is in the vicinity of the centre line of the engine.

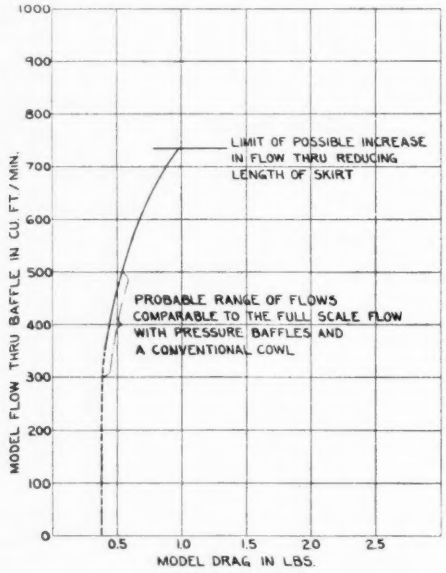


FIG. 21.

General effect of skirt length on flow and drag.

The fact that we believe this increase in drag resulting from an increase in flow in the usual flight range to be typical leads us to an interesting parenthetical conclusion. Five years of general industrial flight-test experience with N.A.C.A.-type cowls have brought forth a maze of contradictory data, resulting in no inconsiderable amount of confusion. This has led to a general suspicion among engineers that there is something mysterious or unpredictable determining the efficiency of engine cowling. Now it may be that the answer is to be found directly in this relationship of flow drag: General flight testing has not given sufficient weight to cylinder temperatures as a measure of flow, and hence of drag. Further research will tell.

Fig. 21 may or may not be correct in indicating relative magnitudes of flow and drag changes. That they are within reason for the flow characteristic is shown by the fact that, using the wind-tunnel data in designing outer cowls, we have arrived at shapes and skirt lengths which co-ordinate well with our general cumulative experience. It is possible to carry through some interesting performance calculations based on curves of this sort. This must be done with caution for several reasons. The tests included only the effect of a flow-measuring baffle simulating an engine mounted in a nacelle. These differences

from full scale are much larger for performance calculations than they are for comparative cowl tests. There is also some question as to scale effect on both drag and flow. Furthermore, any calculation of this type, as the following illustrative one leading to a major conclusion, is based only upon one cowl arrangement modified by cutting off the skirt.

The curve shows that, when the airflow is increased from zero to an amount corresponding to that required for cooling a typical engine, the amount of drag increased. This means that sufficient air to cool the engine caused an increase in the drag of the bare fuselage due to the loss through the engine in combination with the drag at the exit gill. If the engine were assumed to develop the same power in a faster airplane, the flow required from our model—tested at constant air speed—would be less. Therefore, for the faster airplane the increase in drag due to cooling would be less.

For the fast airplane, the skirt length might have to be, say, 21ins., the other features of the cowling being fixed. The slower airplane, however, would not have satisfactory cooling with this type of cowling if its skirt length were greater than 15 ins. The difference in drag between the two cowlings is of the order of 20 per cent. Now in actual practice these two airplanes may be the same; that is, the fast airplane represents the maximum-speed condition of flight, while the slower airplane represents the same airplane in a full-throttle low-pitch climb. This at once suggests the advisability of providing both cowls for the one airplane; in other words, of building a cowl with a variable adjustment which permits a small flow at top speed and much larger flow at climbing speed. The obvious way of doing this would be to design the complete cowling for a cylindrical skirt and simply to slide this skirt fore and aft, increasing or decreasing the size of the exit opening as desired.

This type of variable cooling device would provide improvements of the order of those shown in Fig. 21 and the benefits to be derived from such an arrangement would be considerable. Nevertheless, there were excellent reasons for considering other means of varying the cooling characteristics of ring cowls. One of these was the possible benefits from devices which might be simpler in design and application. Another, and the most important reason, was the desirability of increasing the flow beyond that obtainable with a cowl of variable skirt length in order to be sure of providing for the full range of temperatures encountered with variations of weather and airplane operating conditions.

The curve shows that such an arrangement provides considerable improvements in flow through the baffle by means of shortening the skirt. The limit of cooling with such an apparatus is reached when the entire skirt has been removed. This occurs at a flow only about 60 per cent. greater than might normally be used. The possibility of even being able to vary the skirt length to obtain this 60 per cent. increase in flow is remote because of the mechanical difficulty. It was also desirable to find a means of improving the cooling at a still smaller expense in drag. With these objects in view, other extended tests were run on the wind-tunnel apparatus used for the fixed cowlings. A large number of different arrangements were tried. Only the more interesting of these will be described.

(1) *Varying Skirt Length.*—This device has just been discussed.

(2) *Skirt Trailing-Edge Flap.*—The idea of the flared skirt or flap originated during early flight tests. It was found that incorporating a fixed flared flap at the trailing edge of the skirt, having a length of about 3ins. and giving an increase in rear skirt diameter of abut 2½ins., showed improvements in cooling of 38 deg. and 24 deg. Fahr. on the heads and bases respectively, and a loss in speed of 3 m.p.h. The use of this expedient for reducing cylinder temperatures began and led to the development of the final idea of providing regulated temperature control in the form of a continuous hinged trailing-edged flap, controllable from the cockpit. Wind-tunnel and flight tests will subsequently be described in detail because this mechanism has proved to be one of the best.

(3) *Skirt Trailing-Edge Split-Flap.*—This term is used to mean a variable flapped skirt, such that the inner surface remains at all times in a fixed position while the outer surface can be set at varying degrees of flare.

The results of tests with a split flap showed, in comparison with the results for the same outer flap alone, about half the flow and about the same amount of drag; that is, the split flap is about half as efficient as the full flap. This may be due in great part to the fact that the exit area of the gill was not increased as the flare was extended.

(4) *Sliding Shoulder-Flap.*—A conical piece was made having the same dimensions as the full trailing-edge flap, but located at the trailing edge of the base skirt. In actual operation it would be nested against the shoulder cowl at cruising speed and displaced forward at climbing speed. This arrangement gave, for a given flap size and angular setting, about the same flow as a trailing-edge flap; but it was considerably less efficient, in that its drag was higher. It is doubtful whether this mechanism could be made to produce as high flows as are possible with the full flap.

(5) *Trailing-Edge Protuberances.*—During early flight tests on trailing-edge modifications, it was discovered that slight changes on the outer surface of the cowl might produce appreciable improvements in cooling. Mechanisms might be made which would produce such protuberances in flight, as, for example, an inflatable rubber tube. Wind-tunnel tests on a number of protuberances placed on the upper surface of the after edge of the skirt showed that they are about as effective in producing flow, and about as inefficient in producing drag, as were split flaps of the same height. Rounded protuberances are about the same as sharply pointed protuberances of the same height. Very small ones may be well faired so as to be as efficient as full flaps, but they produce only very small increases in flow. The most efficient of those tried formed a kind of venturi at the gill.

(6) *Annular Gill Forward of Trailing Edge.*—Pressure-distribution measurements in flight made over the outer-skirt surface of an ordinary ring cowl had shown that the pressure was much lower near the centre line of the engine than at the trailing edge of the skirt. Therefore, a wind-tunnel test was run on a skirt which had an annular opening just aft of the centre line of the engine to find whether exit area added here was as efficient as area added by cutting off the skirt. The test showed that the forward annular opening improved the flow nearly as much as was obtained by removal of the skirt trailing-edge, but that the drag increase was larger. It was found that a slight improvement in the efficiency of this arrangement could be made by rounding the after edge of this gill, a conclusion previously reached in flight tests on an allied arrangement. Such an opening might be closed by a sliding annular ring. If it were closed by a hinged flap similar to that used at the trailing edge, an improvement might be obtained. More tests disclosed that this type of flap produces about the same increase in drag as would be obtained with the same flap at the trailing edge, but with, however, considerably smaller improvement in flow.

(7) *Separate Openings in the Skirt.*—A number of equally spaced rectangular openings were cut in the skirt. Openings of this sort could be closed by a rotating shutter. Separate openings of this type were found to be less effective in producing flow and considerably less efficient. Such openings might be closed by doors opening in the manner of flaps. This last arrangement is somewhat less effective than trailing-edge flaps and also less efficient. Nevertheless, doors of this type may be made to produce large increases in flow. Tests with varying number and sizes of doors disclosed that, if the doors are placed too far apart, good cooling will be obtained for cylinders immediately in front of the doors but the cooling of the other cylinder will be much less. Therefore, two or three doors are likely to be insufficient and the use of four or more is preferable.

(8) *Variable-Nose Cowls.*—This term is used to designate only devices which modify the shape of a conventional N.A.C.A. ring-cowl nose. Mechanism for actual use of such an apparatus might be by means of rotating shutters or by doors opening in such a manner as to increase the diameter of the entrance without decreasing the length of the nose. Tests showed that these devices offer little promise of being as effective as devices located on the skirt. The air loads at the nose of the cowl, being many times greater than at the skirt, also add difficulties to the development of such a device. As previously stated, more flow is obtained with a conventional nose than with either a cylindrical nose or with no nose at all.

The use of a conventional nose also results in much less drag. This conclusion was reached after wind-tunnel tests with large flows obtained by means of a trailing-edge flap. Furthermore, in accordance with the processes that produce flow through the baffle, which will be discussed shortly, it is logical to suppose that any change in the cowl shape forward of the baffle can never be made to produce really large improvements in cooling with current skirt designs. This is stated because the most effective variable-cooling cowls obtain their flows by increasing the total pressure drop across the baffle. They have the possibility of lowering the rear pressure by far larger amounts than the nose cowl, which already utilises nearly all of the maximum pressure (free-air dynamic), can ever raise the front pressure. Variable-nose cowls can be used to keep the engine warm in cold weather, but their use is not apt to result in maximum overall cowling efficiency.

The foregoing analysis shows that our search for the best variable-cooling device was by no means cursory, and it indicates that the arrangement which is most satisfactory from an aerodynamic point of view is the variable trailing-edge flap. Fig. 22 shows the effect of flaps in improving flow, and the resultant increase in drag. This curve is typical of flaps, just as the preceding curve was

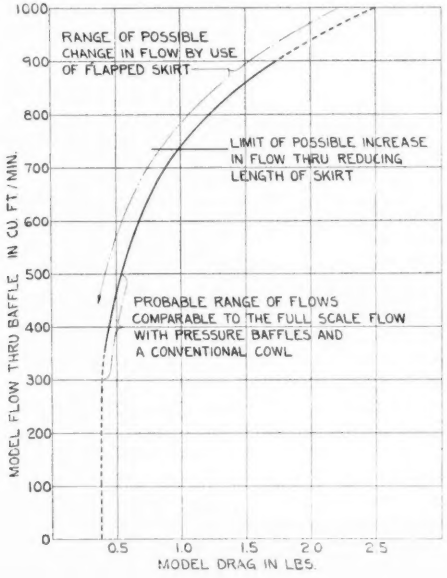


FIG. 22.

General effect of cowl flaps on flow and drag.

typical of the effect of cutting off the skirt. The data for the effect of cutting off skirts are also included on the same curve for the effect of flaps.

The two curves substantially coincide up to the limit of cooling which can be obtained with complete removal of the skirt; and from there on up the flap shows an increasing gain. In other words, a flap which improves the cooling just about as effectively as does varying the skirt length can also be used to obtain much larger increases in airflow through the baffle. These, coupled with the fact that cutting off skirts is as efficient as any known method of improving flow, points unquestionably to the superiority of the flap.

Several different types of trailing-edge flaps were tried as shown in Fig. 23.

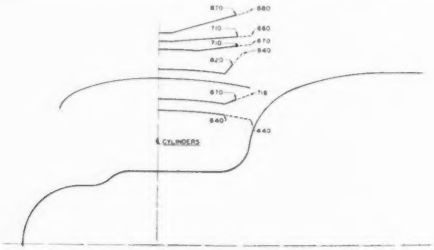


FIG. 23.

Model skirt flap arrangements tested.
The dotted lines indicate flaps cut to different lengths. The model airflows shown are in cubic feet per minute.

All of them were modifications of one base skirt. Three different flap-lengths were tried, and each of these was tested at various angle settings. Each of the flaps was cut off at least once to represent results obtained with flaps on a base skirt which allowed larger flow. The results obtained were consistent with themselves in all cases. Major conclusions comparing different flaps are as follows:—

(1) Hinge point or flap length is a minor variable in determining the efficiency; that is, flow for a given drag.

(2) A short flap turned up to a large angle always produces less flow than a longer flap would at the same angular setting.

(3) Increasing the angular setting of a given flap improves the airflow through the baffle at least up to the range tested; that is 60 deg. from the base skirt.

(4) Even small flaps may produce large improvements in cooling. The curve in Fig. 22 by no means shows the limit. It is merely the greatest amount of flow that was obtained in the tests actually run, and it results from the use of the smallest of the three flaps. The larger flaps turned up to the same angle would probably produce still larger flows. How far this can be carried before there is a reduction in flow or a prohibitively high drag we do not yet know.

The procedure of acquiring and using data on cowls is startlingly analogous to current methods of analysis for wing sections. The similarity includes the use of drag, the use of flow as being like lift, the use of cowl shape and attitude as being like wing camber, thickness, angle of attack and so forth. The analogy may even be carried to the point of breaking down the cowl drag into profile and induced drags, cowl induced-drag being a function of flow, of pressure difference and other variables; and the equations for cowl induced-drag are very similar in structure to those for wing induced-drag. This study will not be carried further here because it relates more directly to forced-air cooling analysis than it does to the design of cowls using only flight-induced flow. Quite possibly,

future work on ring cowls may develop masses of data, and methods of analysis for them, which are as complete and systematic as those which we now employ for wings. But at present both the data and the theory are lacking, and therefore ring cowl design must, for the present, remain on a trial-and-error basis. The best we can do is to give characteristic features of certain cowl shapes and to show what, in general, may be expected of them. This has already been done in this paper, and these remarks show why more detailed instruction cannot now be given for the design of the cowl flaps.

Before discussing the effects of the ring-cowl flaps upon airplane performance and giving flight-test corroboration of the wind-tunnel researches, it may be of interest to mention briefly reasons why the flap so greatly increases the flow of air through the baffle. The analysis of the wind-tunnel test shows that improvement in flow is not a simple function of flap length, hinge point, flap angle, gill exit-area, or increase in diameter of the skirt trailing-edge, or of any simple geometrical variable. The last mentioned comes closest to being a criterion of the amount of flow that will be obtained with different skirts, but use of it underestimates the amount of flow obtained with short steep skirts and overestimates the amount of flow obtained with long skirts set at small angles so as to give the same trailing-edge diameter. This is entirely reasonable, because the flap acts as a deflector for the air in a manner which is obviously too complicated to express in a single geometric factor. The flap not only acts as a valve in providing a variable exit-area at the gill opening, but also as a means of regulating the direction of flow over the skirt such that flaring reduces the pressure under the trailing edge, which reduction in pressure naturally results in an increase in flow.

As has not been stated previously, the wind-tunnel tests included extensive pressure surveys behind the baffle and in front of it. With the base skirt, a type now used frequently for fixed cowls, the static pressure behind the baffle is considerably above free-air static or atmospheric pressure. The static pressure in front of the baffle is of the order of 90 per cent. of the free-air dynamic pressure, and it does not vary much with changes in skirt shape. Thus the front pressure remains high when a flap is used to decrease the pressure behind the baffle. These general conclusions were first observed in flight tests, were then checked in the wind tunnel and rechecked in flight. They are predicated on the assumption that close baffles are used and that all other geometrical features of the cowling and baffling system remain fixed. These observations do not, of course, explain the phenomenon, but merely point out some of its characteristic features.

Considerable space in this paper has been devoted to the acquiring of data on a method for varying the cooling of an aircraft engine, and it has been shown that increased cooling results in increased drag. It has been implied that the use of a variable cooling device will result in improvements in performance, and this is unquestionably true. It will now be shown that it is reasonable to expect gains; after that, flight-test data will be adduced to demonstrate that one expectation has been realised.

Some time ago, aircraft engines were cooled very much more easily than they are to-day. Increases in specific power, and the use of propellers which permit the engine to develop full power in climb, have made the cooling problem more acute. And yet, aircraft designers have been forced, in their efforts to improve performance, to accept the disadvantages of more difficult cooling while making every effort towards improving the drag characteristics of the airplane.

This increasing difficulty of cooling engines may, if not properly allowed for, result in an underestimate of the value of controllable air-cooling. Naturally, there would be a reduction in expected climb performance if a flapped cowl were used on an engine that formerly, at a lower power rating, cooled satisfactorily without it. This is shown by the increases in drag resulting from opening the

flap; but this is not a fair evaluation of the variable cowl unless the resulting improvement in cooling is taken into full account. In other words, the effect on airplane performance of a flapped cowl may be judged solely as an improvement in cooling, allowing for the obvious advantages thereof. This method of evaluation is, however, apt to be confusing, and a more direct presentation of the overall improvement can be shown by considering that the flap is used to maintain constant cylinder temperatures under all conditions of flight. This method of comparison is fair, and it is almost obvious at the outset that it will show improvements in performance.

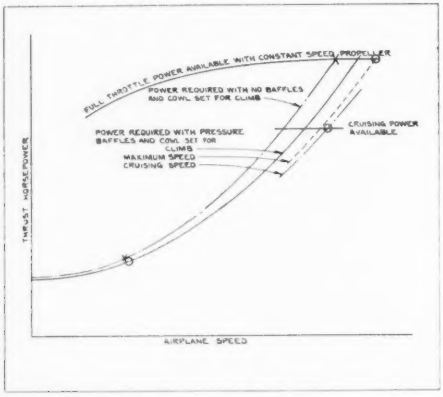

FULL THROTTLE POWER AVAILABLE WITH CONSTANT SPEED PROPELLER
POWER REQUIRED WITH NO BAFFLES AND COWL SET FOR CLIMB
POWER REQUIRED WITH PRESSURE BAFFLES AND COWL SET FOR CLIMB
CRUISING POWER AVAILABLE
MAXIMUM SPEED
CRUISING SPEED
THRUST HORSEPOWER
AIRPLANE SPEED

FIG. 24.

Overall effect of a flapped cowl on performance at constant altitude and cylinder temperature.

Fig. 24 is an illustration of this. For the sake of convenience, the " power-available " curve is drawn for a variable-pitch propeller which permits the engine to operate at constant speed for all full-throttle conditions of flight. In other words, the engine power developed in climb is the same as that at maximum speed in level flight. The " power-required " curve drawn in full is for an airplane equipped with an outer cowl which permits adequate cooling of the engine in climb. As the airplane speed is increased with this same cowling, the heat to be dissipated through the fins remains constant; and yet the amount of air flowing over the fins, and hence the heat dissipated from them, increases considerably. The cylinder temperatures obtained at maximum speed in level flight are thus lower than those with the same cowl and the same power at climbing speed. If it is assumed that the temperatures in climb are satisfactory, then the temperatures at maximum speed are lower than necessary. This is the same as saying that the drag required to cool the engine is larger than necessary.

Suppose now that the cowl is altered in such a way as to reduce the airflow to an amount just sufficient to cool the engine at maximum speed, but not in climb. The preceding analysis has shown that there will be a reduction in airplane drag if both cowls are reasonably well designed. The next lower power-required curve in Fig. 24 illustrates the change in drag of the airplane due solely to this adjustment of the cowl.

At cruising speed the second cowl furnishes more cooling than is required to maintain the satisfactory cylinder temperatures. This results from the fact that the heat dissipation is reduced roughly directly as the air speed, while the heat to be dissipated is reduced approximately as the cube of the air speed. In other words, the cowl which gave just adequate cooling at maximum speed

furnishes an unnecessarily large amount of airflow, and hence drag, for cruising speed. There is thus a further gain to be obtained from designing a third cowl, especially for the cruising condition. The approximate relationship among these three cowls is shown on Fig. 24.

Now these three cowls can be considered as three different positions of an adjustable flapped cowl. While there might be slight improvements in an especially designed fixed cowl over those of a flapped cowl at extreme positions, our test work shows that this is not likely to be the case and that the variable cowl efficiently fulfills the purpose of three or more well-designed fixed cowls. The uppermost curve in Fig. 24, showing the power required without close baffles and with a fixed cowl set to cool in climb, completes the illustration of the overall gain due to using the entire baffling and cowling system which this paper discloses.

These curves were obtained from calculations based on the use of the equation showing the effect upon cylinder temperatures of the major variables, judicious use of the wind-tunnel data, and cumulative flight-test experience. Systematic calculations of this sort show that the magnitude of the gains in performance which should be expected will be considerably influenced by the type of airplane, by the cooling characteristics of the engine, and by the design of the ring cowl necessary for the base case; therefore, we hesitate to give an estimate of the magnitude of overall gains except in cases where actual test data are available.

Fortunately, even before the data were made available from the wind-tunnel tests, the possibilities of the controllable flapped cowl were sufficiently apparent to warrant the design and construction of such an arrangement for installation on the Vought V-70-A airplane. Figs. 25 and 26 show this installation with

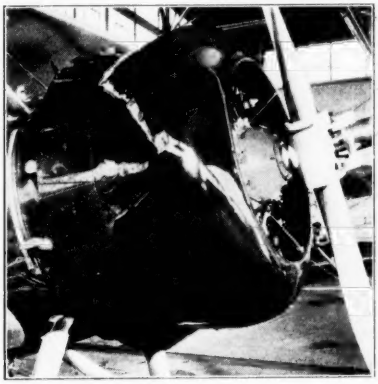


FIG. 25.

Open position of controllable cowl flaps as installed on a V-70-A airplane equipped with a "Hornet" engine.

the flaps in the full-open and in the closed position. Some flight tests of these flaps have just been completed (Jan. 20, 1934) and the results of these tests are shown in Figs. 27 and 28.

The level-flight tests were conducted at a constant density-altitude above sea level and at a constant engine power less than rated to eliminate the effect of density upon heat dissipation and airplane drag. The use of a power less than rated, done for convenience of test procedure, resulted in speeds less than the maximum for this airplane. To check the speed effect of opening the cowl, the

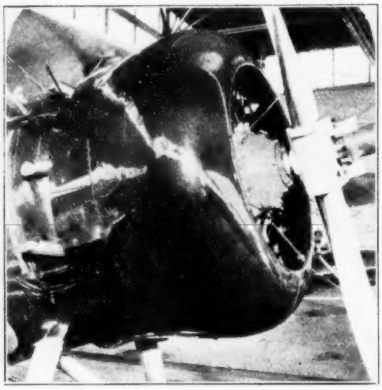


FIG. 26.

Closed position of controllable cowl flaps as installed on aV-70-A airplane equipped with a "Hornet" engine.

airplane was flown full throttle over a speed course. These data, shown as the uppermost curve in Fig. 27, verified the previous results.

Fig. 27 shows the changes in cylinder temperatures and changes in airplane speed resulting from changes in the angle of the flap, at, in all cases, constant engine power. A definite trend in confirmation of expectations and of the model results is apparent. Since we have constant power in all cases, the heat to be dissipated by the fins is also constant. Any changes in cylinder temperatures therefore are due entirely to changes in flow through the baffles. That increasing the angle of the flap definitely increased the flow is apparent from the progressive lowering of cylinder temperatures. This occurred in spite of the fact that the flow due to flaps alone was reduced by a drop in airplane speed. The drop in air speed correspondingly resulted from progressive increases in drag as the flaps were extended. In other words, the flight tests showed a large and continuous increase in airflow through the engine accompanied by some increase in drag as the flaps were extended exactly as shown in the wind-tunnel tests. The flight tests also show that small deflections of the flap from 0 deg. setting improve cooling with little loss in speed and that the drag increases at a faster rate as the flap is extended. It also clearly indicated from the curves that further improvement in cooling at an increased rate (based on flap angle) could have been obtained by further extension of the flaps beyond the 20 deg. used.

An examination of the dimensional changes resulting from extending the flap 20 deg. indicates that, even with flap extended, we have a cowl that should compare quite favourably with fixed cowls obviously designed to take care of a difficult cooling problem. The total cowl length is 32ins., the last 9ins. being the chord of the flap. Extending the flap to 20 deg. increases the radius of the trailing-edge skirt only 3ins. and its angle to the thrust line become 15 deg. The gill opening is increased from about 3ins. to 5ins. This last figure is quite reasonable for a fixed-cowl installation which is difficult to cool.

Examining the climb curves, in which the engine powers are comparable to the usual relationship between climb and high-speed conditions of flight, the change in cylinder temperatures between 0 deg. flap and 20 deg. flap-setting is 50 deg. Fahr. for heads and 25 deg. Fahr. for bases. This, incidentally, is checked by other flight tests. At the same time, we find that the difference in temperatures at high speed, for 0 deg. flap and 20 deg. flap, is 60 deg. Fahr. for

heads and 30 deg. Fahr. for bases. The advantage, as pointed out in the analytical discussion, of substituting a controllable flap on an airplane requiring, for adequate cooling in a climb, a fixed-cowl arrangement corresponding in effectiveness to a 20 deg. flap-setting on the V-70-A, is apparent from these flight tests. With the controllable cowl, the flap should be set at 20 deg. for climb to obtain the required cooling and pulled into 0 deg. for high speed. The engine

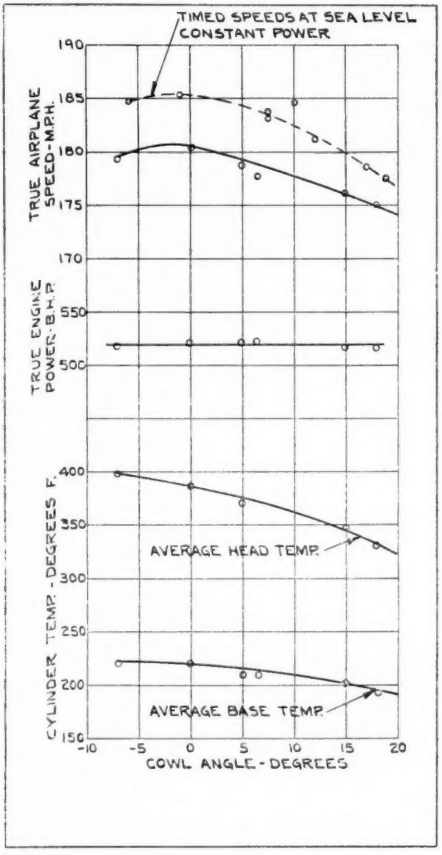


FIG. 27.

Results of flight tests with a flapped cowl in level flight at constant-density altitude at 2,000ft. on the V-70-A airplane.

temperatures at climb and at high speed will be about the same, and the gain in top speed is, for an airplane whose speeds are comparable to the V-70-A, 6 m.p.h.

The question arises, however, of the effect on rate of climb of extending the flap. The climb data obtained in connection with the temperature readings shown in Fig. 28 have been plotted, and the flight-test notes of climb obtained at sea

level are: 1,720ft. per min. with a cowl angle of 0 deg., and 1,660ft. per min. with a cowl angle of 19 deg.

The decrease in climb attributed to the flap is only 60ft. per min., or 3 per cent. The loss in rate at higher altitudes remained about the same, but at 5,000ft. the temperatures began to drop. By gradually pulling in the flap as the altitude is increased, a point will be reached where the flap is at 0 deg. angle and no loss in climb will occur. The airplane ceilings, therefore, will be about the same.

It should be pointed out that, even in the experimental set-up used on the V-70-A, the advantage of the flaps is clearly shown in that this airplane cannot be expected to cool entirely satisfactorily in a full-power climb at 90 deg. Fahr. ground temperatures without using the controllable flap. The average head temperatures for 90 deg. strut air-temperature can be expected to run up to

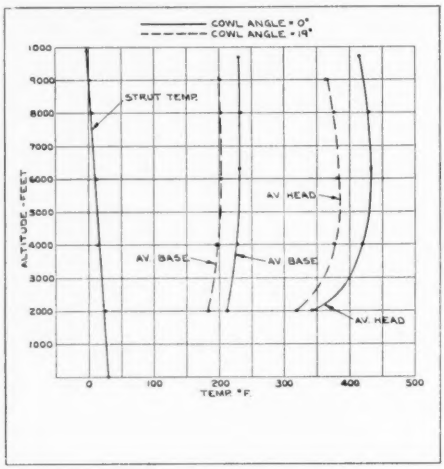


FIG. 28.

Results of climb tests with a flapped cowl at constant air speed with the V-70-A airplane, with the propeller set for the same power and number of revolutions per minute in level flight at sea level.

535 deg. Fahr. with 0 deg. flap, but can be dropped to the very satisfactory value of 485 deg. Fahr. by extending the flap to only 20 deg. At full speed in level flight, on the other hand, with flaps closed, the head temperatures at 90 deg. strut will be about 515 deg. Fahr. Opening the flap slightly at this high ground temperature will reduce the temperatures to 500 deg. Fahr. with a loss in speed of 1 to 2 m.p.h. Rather than indicating an undesirable cowl arrangement at the 0 deg. angle setting, it appears on the contrary that, because cruising permits lower flap-setting than maximum speed, the arrangement is really what we are desirous of obtaining; for example, the most efficient basic arrangement (near 0 deg. flap) that will give the required cooling at cruising speed, at high summer air-temperatures. This is based on the assumption that we are primarily interested in the most efficient performance obtainable at the horse-power decided on for cruising speeds.

The foregoing remarks deal for the most part with the possibilities of the use of the controllable flap for different performance conditions. They also point to the equally desirable possibilities of the flap in connection with seasonal air-temperature

variations. Not only can the flap be controlled to improve the performance of the airplane during winter in comparison with summer operation, but the temperature of the engine can be adjusted at will to operate, regardless of air temperature, at its most efficient temperature. It will be desirable to lower the cylinder temperatures in summer and to raise them in winter. During recent cross-country flights of the V-70-A, it became second nature for the pilot to regulate the engine temperatures by adjustment of the flap, with entirely satisfactory results. The possibility of being able to control the engine temperatures on a bi-motored airplane during accidental single-engine operation is equally desirable, since slight loss in the speed due to flapping the cowl is unimportant provided the engine continues to function properly.

It should be made clear at this point that the improvements in performance and other advantages of the controllable flaps, as definitely shown by the curves of Figs. 27 and 28 are, due to the limitations of the tests, merely indicative of the improvements possible and should not in any way be considered as indicative of the limits of improvement. The results are based on a:—

(1) Single airplane and a single engine;
(2) Single cowl installation;
(3) Single length of flap;
(4) Small extreme angular displacement of flap;
(5) Single gill opening at 0 deg. flag; and
(6) Small variations in air temperatures on a moderately cold day.

With data available on the foregoing items as variables and on the combinations of these variables, the ultimate improvements resulting from the use of the flaps should be greater than the results of these few tests indicate.

In closing the discussion of the controllable cowl, we note the analogy between the use of a retractable radiator on a water-cooled engine installation, and the controllable cowl flaps on an air-cooled engine installation. The functions of the two are identical; that is, to improve the overall performance of the airplane and, at the same time, to regulate engine temperatures according to seasonal variations in strut temperatures.

Other Items of Power Plant Installation.—During the flight tests with pressure baffles, certain changes were found to be desirable and other interesting conclusions were reached.

In the early pressure-baffle installations, the air intake opening to the carburettor was located aft of the gill, and, although the quantity of air leaving the gill is less with pressure baffles than without, its temperature is correspondingly higher. The normal increase in temperature of the air to the carburettor over the strut temperature was increased, and increases as high as 100 deg. Fahr. were observed. To lower the temperature of the air entering the intake, the air duct was led forward through a baffle between adjacent cylinders. The rise in intake air temperature over the strut temperature was thereby reduced to around 5 deg. Fahr. At the same time the air-pressure boost was increased to a value corresponding to that with the best ramming-head installations.

It was at first believed that taking air away in front of the baffle diaphragm would affect the cylinder temperature; but, fortunately, test data showed that this was not the case. In other words, there is a difference between air leakage from the front to the rear of the baffle diaphragm and in leading air away from a point ahead of the diaphragm, provided the air does not exhaust into space aft of the baffles. In the case of the air intake, the air is led to the carburettor. The effect is very similar to that produced by a slight reduction in the size of the front cowl opening. The effect of a correspondingly large leak hole, however, is to raise the pressure behind the baffles, thereby reducing the pressure difference between front and rear face of the baffle diaphragm and hence lowering the velocity of the air flowing through the fins.

The method of carrying the air intake through the baffles can be used very effectively on the single-row installations. On the two-row installations, it becomes more difficult due to limited space; but, in any event, if special provision is not made to take in outside cold air *ahead* of the gill opening, the temperature of the intake air probably will be so high as to lower materially the power of the engine. The foregoing remarks also apply directly to oil-cooler installations where it is even more desirable to provide high velocity cold air through the oil radiator.

As previously mentioned, it was found desirable to enclose the rear end of the engine and accessories in a tight-fitting cowl to keep the temperatures in this compartment as low as possible. Further improvement in this respect was obtained by leading small tubular air ducts through the baffles back to the rear compartment, with the exit from these tubes directed to the magnetos which, even in the usual conventional installation, may become too warm to operate most effectively.

The use of complete exhaust collectors is becoming more or less standard on all power-plant installations. As previously pointed out, obstructions in or near the gill opening should be avoided. This has a bearing on the location of the collector. It should be located well away from the gill opening, such that the influence on flow is a minimum. There are at least two possible solutions which will accomplish this; one is to locate a collector having a diameter equal to, or greater than, the exhaust port circle, in the space just to the rear of the exhaust ports. The collector should clear the cowl skirt by a reasonable amount so as not to obstruct the airflow from the rocker box fins and also to provide cooling for the collector itself. The collector in this location will give the least obstruction to flow from the baffles and through the gill. The foregoing can be used most effectively where the cowl arrangement permits of the use of a long skirt.

The second suggested placement of the collector, which can be used on either single or two-row installations, but is especially adaptable to the latter, consists of housing or burying the collector in the shoulder. The shoulder contour is set up as usual and a D-shaped duct formed by the face of the shoulder and an added circular rear section is provided to house the collector. The individual exhaust stacks lead to the collector proper, through holes provided in the shoulder. The resulting annular space around each individual stack provides entrance for cooling air to the collector proper and, by leading a duct from the housing to the carburettor, an excellent hot air stove using this air is provided. In arranging the valve or butterfly admitting hot air to the carburettor, means should be provided to permit a liberal flow of air through the housing for cooling when not using hot air.

The use of individual short stacks without a collector ring influences the choice of best cowl skirt. Some allowance should be made for the reduction in gill opening due to the presence of the stacks, and they should be arranged to give a minimum of aerodynamic disturbance.

While it is not intended to go deeply into the structural design of N.A.C.A. cowls, the following data will be of interest. In conjunction with the tests of pressure baffles on the Vought V-50 with the 3:2-geared 1690-D Hornet engine, pressure distribution measurements were made across the fore-and-aft length of the N.A.C.A. cowl. These pressures were taken on both the inside and the outside of the cowl. The normal values obtained were plotted on the cowl contour and then integrated to give both the total forward force over the complete cowl and the total force tending to burst the cowl. The tangential forces were, of course, not measured, but in any case they will be of relatively small magnitude.

The results showed higher loads with pressure baffles than without and the magnitudes were surprising. At 167 m.p.h. indicated level flight speed, the total forward force was 680lb. and the total hoop tension was 375lb. These loads were obtained for a cowl of 55in. outside diameter and 23½in. total length.

Although the loads given are for the total length of cowl, almost all of the entire load was concentrated ahead of the pressure baffles. The fact that these loads must be given serious consideration in cowl design in the event of high diving speeds is clearly shown by the fact that the loads at 400 m.p.h. increase to 3,900lb. forward load and 2,160lb. hoop tension. It should also be pointed out that the forward force at local points may well be appreciably greater for a yaw condition.

As previously pointed out, the aerodynamic loads on cowl trailing-edge flaps should be easier to design for than the loads on nose flaps. This is analogous to the relative unit loadings on wing flaps as against wing slats. Although no test figures are available for the loads on controllable cowl flaps, considerable flight testing with the first one built indicates that they can without doubt be provided for adequately.

The adoption of any new device as a means of improving performance is predicated, in most cases, on the weight involved due to its installation. The weight increase, in the case of the V-70-A airplane, due to the installation of the flaps, control mechanism and supports, was 23lb. This installation, being decidedly experimental and built only to obtain flight test data, was heavier than need be. Two other designs recently completed show a weight increase due to flaps of only 14lb. and 16lb. Considering the device only as being equivalent to an increase in horse-power, we find in the case of the V-70-A that the increase in power necessary to improve the high speed 6 m.p.h. (as the flaps did) will be of the order of 60 b.h.p. Even at 1.3lb. per b.h.p. the controllable flap more than pays for itself. However, emphasis should be placed on the fact that, whereas an increase in engine power not only calls for an increase in weight of the engine, but an increase in weight of structure and other items of the vicious circle, the controllable cowl flap is entirely a drag-reducing device and the weight increase to the airplane resulting in the use of these flaps is only in the device itself. In addition, the ability to be able to regulate the engine temperature for varying weather conditions is in itself worth some weight increase.

In conclusion, we are glad to acknowledge the friendly interest and encouragement of the United States Navy in this as in so many other united research projects. We would also like to thank the staff of the Aeronautics Department of the Massachusetts Institute of Technology for its valuable work in conducting the wind tunnel tests.

Conclusions

The results of the study show that much can be done to improve the arrangements now in general use by the proper design of engine baffles and cowling. Conclusions as to the type of engine baffling and cowling system which has been found best are given below. These conclusions are advanced as the result of analytical studies, wind tunnel work and flight testing, and it is probable that operating experience will verify them; nevertheless, they should be accepted as suggestions rather than recommendations.

Engine-Cylinder Baffles

(1) Baffles of the pressure type usually give better cooling than a ring cowl without baffles and they often provide better cooling than is obtained with no baffles and no ring cowl.

(2) These baffles, when used in conjunction with properly designed cowling, produce a considerable improvement in airplane performance.

(3) The function of the baffle is to direct all air which flows through the circumferential circle of the engine so that it passes over the cooling surfaces.

(4) The baffles should direct air to the after quarters of the cylinders only. They need not extend forward of the centre line of the barrels and they may extend

aft so far as to leave only a small opening. The rear edges of the baffles should nearly touch the fins and the front should be spaced slightly farther out.

Engine Cowling

(1) The engine cowling system which is most suitable for use with pressure baffles is very similar to that originally recommended by the N.A.C.A.

(2) The nose of the ring cowl should have an opening diameter of around 80 per cent. of the engine diameter. The nose should have a smooth entry, fairing in to a plane perpendicular to the thrust line. Slight differences in nose shape affect efficiency only slightly.

(3) The after skirt of the ring cowl should be approximately on a line fairing the nose and shoulder cowls smoothly.

(4) The shoulder, wrapper, or accessory cowl should fair into the fuselage in a smooth curve. It should extend quite far forward to provide as smooth an exit as possible.

(5) Variations in cowl shape may, without producing large variations in overall efficiency, cause very large variations in airflow through the baffle with resulting changes in drag. In fact, the amount of cooling air which a given cowl permits to flow through the baffles is one of the most important factors determining its drag. This indicates that (*a*), the cowl should be designed to furnish no more than adequate cooling, and (*b*), previous contradictory test results may be explainable by this hitherto neglected phenomenon.

Controlled Air-Cooling

(1) Controlled cooling, to provide adequate cooling for variations in air temperature and to reduce engine drag to a minimum for each airplane and engine operating condition, is highly desirable.

(2) A cowl having a skirt composed of a series of separate flaps with a mechanism for flaring them in flight, fulfils this requirement satisfactorily.

(3) A relatively short flap, adjustable through small angles, provided a range of cooling adequate to cope with variations in weather and conditions of flight.

Other Items of Power-plant Installation

(1) The exhaust collector should not interfere with the exit flow and yet should receive sufficient cooling air.

(2) Special provision should be made to prevent overheating of the accessory compartment.

(3) Carburettor intake air in most cases should not be drawn from behind the baffles where the pressure is low and the temperature is high.

The 575th Lecture read before the Royal Aeronautical Society since its foundation, January 12th, 1866.

A meeting of the Royal Aeronautical Society was held at the Royal Society of Arts, John Street, Adelphi, London, on Thursday, March 15th, when a paper by H. J. Pollard, Wh.Ex., A.F.R.Ae.S., on "Some Developments in Aircraft Construction," was read. In the chair: H. E. Wimperis, Esq., C.B.E., F.R.Ae.S., Director of Scientific Research, Air Ministry.

The CHAIRMAN: There was little he need say by way of introduction of Mr. H. J. Pollard, because his work was so well known to members. Mr. Pollard began life from the aeronautical point of view in the office of Messrs. Vickers and had valuable experience there under Mr. Pierson. He subsequently had experience with Mr. North and later was associated with Captain Barnwell at Bristol, and it would be agreed that to have worked with three such well known individual designers as these was a very happy experience for any aeronautical engineer to have had. Since he had been with the Bristol Company, during the past 12 years, Mr. Pollard had been engaged on metallisation but, as no doubt would be said during the lecture, metallisation was very far from meaning taking out the wood and putting in metal of the same design.

SOME DEVELOPMENTS IN AIRCRAFT CONSTRUCTION

BY

H. J. POLLARD, Wh.Ex., A.F.R.Ae.S.

Introductory

When the Council invited me to read a paper before the Society they suggested as the subject, "The Use of Steel in Aircraft." After some consideration, I came to the conclusion that there was not very much new and interesting to say on the use of steel in structures, but that there was a good deal to say concerning the use of light alloys in special constructions. Not that I claim that what I have to say is new, but the particular use of light alloy sheet to be described certainly merits more consideration than it has so far received in England. It is not to be inferred that I think that the use of steel is likely to decline rapidly, on the contrary, I am of the opinion that it will always be widely used. Everyone seriously engaged in the technical side of the industry knows that steel of various grades has been used in aircraft from the beginning of aviation and has been the subject of intensive studies during the last fifteen years. It was obvious from the first that if high stresses could be realised with fair uniformity in the finished structural members—say 35 tons per sq. inch or higher—more economical use of steel on a weight-strength basis could be made than of any other material. However that may be, I shall only touch on steel and its uses in construction at one or two points in the course of the lecture.

As aircraft and engine design has progressed, the question of structure stiffness has come more and more to the forefront, until now it may assume a prominence equal in importance to considerations of strength. Along with the requirement of increasing stiffness is the ever-insistent call for lower drag, thus the attainment of stiffness in the wings through the use of external bracing is the answer to only part of the whole problem and designers are forced to consider the possibilities of constructions in which as much as possible of the stressed

material is placed at the greatest distances from the neutral axes, and it is mainly about that aspect of aircraft construction that I wish to speak to-night, in other words, *stressed skin constructions*.

In order to keep practical considerations to the fore, my remarks will, so far as possible, be associated with parts of actual aircraft. From the viewpoints of cost, handling, manufacture, etc., minimum thickness of material is an important matter; and as we shall soon see that steel cannot compare with light alloy as the material for coverings we will straight away fix the minimum practicable thickness of the latter at 0.02in.

Elements of Fuselages in Compression

We will consider first the fuselage of any normal aeroplane under combined bending and shear forces, and imagine this skin of material, 0.02in. thick, laid over the surface and that all the original internal structure is removed; then assuming that the simple bending theory is true (which in fact it is for small loads and low stresses) we can determine the maximum stresses in the skin caused by, say, the vertical component of the skid loading. We shall find that these stresses are anything from, say, 2 to 6 tons per sq. inch. It would, of course, be possible to invent exceptional cases where the induced stress would be higher or lower than that, but exceptional cases are not taken into account in this paper.

Some bending tests have been made in America on large diameter duralumin cylindrical shell constructions of true monocoque type, *i.e.*, skin attached to

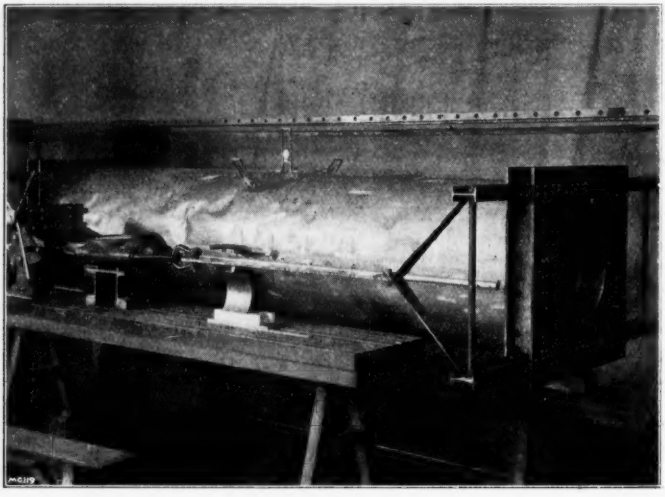


FIG. 1.

Surface in compression. Elastic buckles. Permanent buckle at one stringer.

transverse stiffeners for the purpose of getting the desired shape, but having no longitudinal reinforcement and the stresses developed (Ref. 1) fitted the formula

$$Fb = 3{,}000{,}000/(r/t) = \text{Failing stress lbs. per sq. inch}$$

and r/t = Radius of cylinder/Thickness of walls.

The curvature of the upper and lower parts of many small and medium sized fuselages is such that if the ratio of the approximate radius of curvature to

the least practicable sheet thickness is used in the above formula, the resulting *Fb* is in or near the range of stress quoted.

Reinforcements

From this consideration it would be necessary to use little, if any, stiffening for the sheet covering, particularly in cases where the diameter to thickness ratio is of the order of 1,000, but as practical constructions only are involved the skin must be reinforced, if only against handling. By reinforcement hoops and stringers of angle, channel or other suitable section, riveted or otherwise secured to the skin are implied. Since the drag must be the lowest possible, we must rule out corrugated sheet, a smooth exterior being essential. If corrugations are considered necessary, a sheet so formed must be for internal structure only, a point which is dealt with later in connection with a type of wing structure.

It follows from the foregoing that in the case of the fuselage, we are concerned only with relatively wide spacing of reinforcements, say 300 times the thickness of the covering material or wider. With some such figure as that in mind, we can discuss very briefly the behaviour of a reinforced sheet under load.

Needless to say, a reinforced sheet would buckle between the reinforcements when subjected to compressive, and/or shearing loads, of sufficient amounts. Collapse does not occur, however, with the formation of the buckles, since the sheet between stiffeners will always deform a great deal before the collapse of the stringers occurs; this point is well illustrated in Fig. 1, whilst Fig. 2 shows

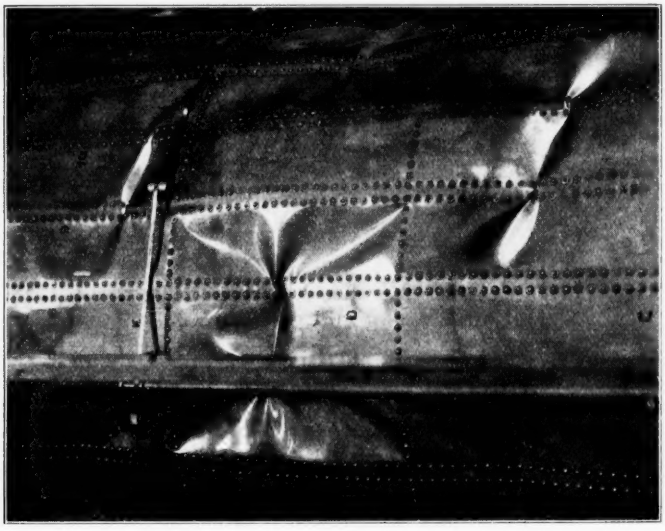


FIG. 2.

Appearance of surface when stringers buckle.

that failure is bound up with the collapse of the stringers. We are thus obviously not much interested in the ultimate failing load of unsupported sheet under compressive forces, but the determination of the buckling load of sheets is of great importance, having regard to appearance and drag.

The problem to be solved then is the stability and strength of combinations of stiffener and sheets. Taking first compression (*e.g.*, the upper surface of the fuselage in the skid load case); for practical purposes it is usual to assume

that a certain width of sheet, attached to a stiffener is fully effective in carrying load and the remainder is wholly ineffective. The strut strength of stringer plus effective sheet is estimated and the moment of resistance of the whole section computed about appropriate axes. The difficulty, of course, lies in determining the effective width of sheet, the following relation (due to Professor Theodore von Kàrmàn) between the various factors comes in useful for the purpose.

$$2w = C\sqrt{(E/p)}\,t$$

where $2w$ = effective width of sheet.
p = crippling stress at failure.
t = thickness of the material.
E = Young's Modulus of the material.
C = a constant.

The derivation of the equation is fully described in Ref. 2. This matter is also dealt with in Ref. 3, while in the third part of that paper an expression is given for the effective width of strip extending either side of a hoop stiffener in a circular cylinder.

In the case of skin terminating beyond a stringer, the formula for the effective overhang is the same as the above in form but with, of course, a different constant. Three methods of calculating the compressive strength of flat sheet and stiffener combinations are given in Ref. 4, where it is shown that the method based upon mutual action of the stiffener and an effective width of sheet acting as a single strut, gives results in best agreement with experiment. We also have obtained good agreement between our calculations using the method (as described in detail in Ref. 4) and experiments made in Bristol.

The above has reference only to reinforced flat sheets or reinforced sheets having small curvature. Incidentally, for reasons given in Ref. 4, these latter may support 10 to 15 per cent. less load than otherwise similar flat sheets. The matter becomes more involved when stringers are attached to sheets, of larger curvature and consequent greater stability, but which still fail through wall instability (at values of r/t lying, say, between 1,000 and 100); an attempt (empirical) is being made to solve this problem by interpreting the curved-skin stiffener combination in terms of a skin of "equivalent thickness."

Referring only to flat or surfaces of small curvature, it follows from the information available, that an average pitch for the stringers enabling the whole of the skin to be effective would be approximately $100t$, and a closer pitching would not result in greater stress development in the skin.

Questions of increasing the strength of the fuselage by decreasing the space between the hoops, or deepening the stringers, or both, thus decreasing the slenderness ratio of the stringer-skin combination, cannot be usefully treated in a general way. A strut curve for the sheet-stiffener combination chosen will, of course, give some guidance. The factor of cost must be taken into account in settling the spacing of hoops, but the pitch should not exceed one half the average diameter of the body; the spacing of stringers may be the more important matter. An investigation in regard to the optimum spacing of hoops has not, so far as I am aware, yet been started, and is rather overdue.

Elements of Fuselages in Shear

As to the behaviour of reinforced sheet in shear, we can consider the sides of the fuselage under the upward force which produced the compression in the upper surface of the body.

The sheets forming the sides of the fuselage behave in the manner shown in Fig. 3. It will at once be noticed that the shear buckles formed differ appreciably from the compression buckles (Fig. 1), those due to shear run diagonally across the panels from corner to corner, while those due to compression appear as troughs centrally disposed between the four bounding reinforcements

of each panel. Clearly, if the sheets were removed from the sides of the fuselage we should expect the structure to collapse, since the only resistance to deformation would be that due to local stiffness at points of crossing between stringers and hoops. Since it is quite good practice to leave the stringers and hoops unconnected, we can say that the sheet carries the whole of the shear load and that the reinforcement has to resist all the components of force from the pull of the sheet.

The diagonal shear waves have a special significance; we can be quite certain that if they do not form as the full factored load is being approached, then either the sheet is too thick or the reinforcement is too closely spaced; this point will be demonstrated later. Their appearance, moreover, is an essential condition for the application of a simple method of strength calculation for members in shear (due to Professor Wagner) which is very briefly outlined later.

There is another point about these waves, and that is the effect on the people

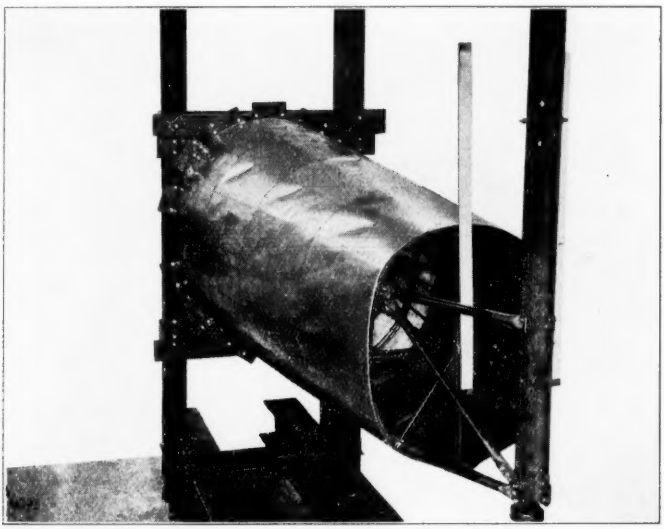


FIG. 3.

Monocoque fuselage subjected to combined bending and shear.

who see them. Their appearance can scarcely be expected to fill the uninitiated with confidence—consequently a limit must be set to the applied load, below which no buckles shall occur in external members in either shear or compression, and I would suggest that the minimum load should be one-third of the fully factored load.

Buckling Stresses in Thin Plates

The difficulty lies in estimating the buckling load, *i.e.*, the load at which the thin metal becomes elastically unstable. This matter had little more than academic interest until brought into prominence through this use of thin metal covering on aircraft.

Numerous investigators have shown that for plane and corrugated panels in shear or compression the critical stress may be expressed in the form

$$p = kE\,(t/b)^2$$

where p = critical stress.
E = Young's Modulus.
t = thickness of sheet.
b = width of sheet.
k = constant.

A list of the cases solved (with the references) are shown in the table at the end of the first appendix.

Taking appropriate values of Young's Modulus and density, we can, with the aid of the formula, quickly place the various structural materials (used as panels and loaded in the plane of the panels) in their order of merit. Other questions in addition to critical instability have to be considered before arriving at a decision on the choice of material, but the high density of steel renders it unsuitable for use in panel type structures, for although the value of E is approximately three times that of the structural aluminium alloys, yet the latter

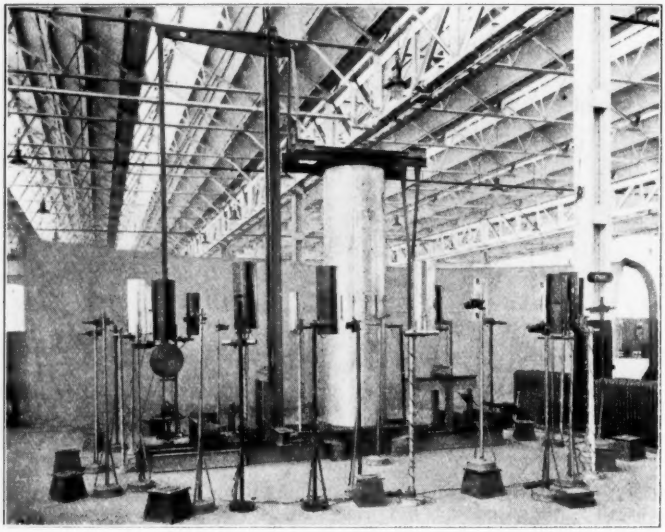


FIG. 4.

General view of reinforced cylindrical shell construction undergoing test.

can be approximately three times thicker than the former for the same weight of panel, and the buckling load increases as the cube of the thickness. From these considerations only, three-ply is the best material to use. At the moment it does not seem probable that the many desirable properties that steel possesses will outweigh the very definite disadvantage of weight. High stress development is essential for the economic use of steel.

Attention is here drawn to R. and M. 1553, published about two months ago. Title, "Summary of the Present State of Knowledge Regarding Sheet Construction," by H. L. Cox, B.A. Mr. Cox has succeeded in placing a large amount of valuable information in comparatively few pages, thus rendering it easy for anyone to become conversant with results and with the many problems still unsolved on thin sheet construction.

The question may arise as to which formula (2) or (5) given at the end of the first appendix is appropriate when dealing with slightly curved surfaces. In this connection it has been observed from experiments that in the case of metal wing or fuselage covering where the t/r ratio has been small, that either the flat plate or the round tube formula could be used with about the same error.

This problem has been investigated by Mr. S. C. Redshaw, M.Sc., of the Imperial College Civil Engineering Staff, and his work on the subject has very recently been published as an R. and M. No. 1565. Title, "The Elastic Instability of a Thin Curved Panel subjected to an Axial Thrust." The first appendix includes the basic formula derived by him, and the formulæ for the extreme cases of a flat plate and a plate having a definite curvature are deduced from that. The critical stresses for any curvature can quickly be obtained by substituting the constants obtained from the graphs in the appropriate formula.

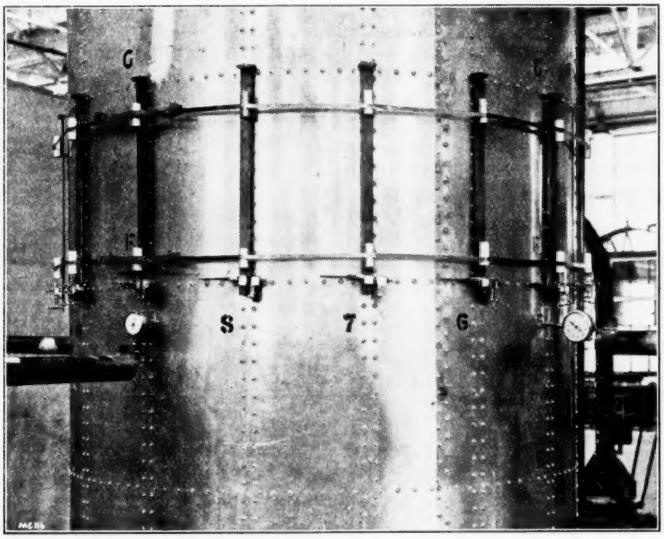


FIG. 5.

Extensometers used for strain measurements at stringer positions.

Redshaw's results prove directly that it is fundamentally sound to estimate the strength of a large component, for example, a monocoque fuselage, from a test on a small element representing the construction at the most highly stressed part. The theoretical critical stresses are practically independent of the length of the specimen, and a test specimen having the correct curvature and breadth and of a convenient length may be easily constructed and tested by applying loads, moments and shears of the values which would obtain at that particular section of the whole component; a great practical advantage over constructing and testing a whole fuselage.

Incidentally, Mr. Redshaw has applied his analysis to certain quadrantal specimens of monocoque constructions which have been tested, and the theoretical critical stress given by Formula 3 in the appendix was in most cases 80-90 per cent. of the collapsing load recorded on the test log sheet.

I do not wish to give the impression that the problem of the strength and stiffness of reinforced smooth sheet constructions has been completely and finally solved; that is far from being the case. I can, however, take this opportunity of stating that investigations are being actively pursued on the subject in the Bristol Works on behalf of the Directorate of Scientific Research. Figs. 4 and 5, showing a general view of a test on a cylinder and a " close-up " of the strain measuring gear respectively, are evidence of this.

Before leaving fuselages, it is opportune to say that one of the troubles in preparing a short paper on a big subject is not what to put in, but what to leave out; thus as regards the design of rigid bulkheads necessary at places of attachment of wings, undercarriages, tail wedge, etc., I must refer you to Refs. 5 and 6; further, no comments will be made on the subject of monocoque versus girder constructions for those fuselage parts subjected to concentrated loads, or for those portions in which considerable interior accessibility from the outside is a specified requirement. As to the all-important matter of holes in the covering, cockpit openings, port holes, doors, windows, and the like, one can only say that the matter is the subject of investigation at the present time; a few experimental results are given in the second appendix in relation to holes in square sheets subjected to shear. This work has not proceeded far enough for the establishment of formulæ, and while relatively small holes may be of small consequence, yet for the present, in the case of really large apertures for doors, etc., design must be based on experiment or experience. It would seem that a mathematical analysis of this problem must be based on experimental investigation, *e.g.*, elastic failure of sheets of constant size could be plotted against size of hole, the size of sheet, reinforcement, type of loading, etc., being constant. Probably a law could then be established for this case. Similarly, other laws might be established between all the variables in turn, the whole being perhaps ultimately correlated. Moreover, if mathematical support could be given to any of these experimentally established formulæ, the field of design would no longer be limited to the experiments made. For example, if in a new design of a fuselage an aperture was required much greater in area than any used during the course of the research work, and a proof stress check was considered necessary on the finished structure, then the chance of success would be much greater than would be the case if the new design were based on a few experiments unconnected by logical deduction.

Elements of Wings in Shear—" Tension Diagonal Fields "

As a preliminary to the consideration of wing spars and wing covering, we will return briefly to the problem of reinforced sheet in shear. The basic conception has already been defined, that is, the buckling of a plate web into a diagonal series of waves which Wagner calls a " tension diagonal field." The vertical and horizontal components of shear stress set up in the plate on the first application of a small shear load have, as shown in the elementary theory of structures, a tension stress component and a compression stress component acting at right angles to the tension stress. The sheet is so thin that it cannot resist much compressive stress, and this latter causes deformation into a series of waves, the crests and troughs being of course in the direction of the tensile stress.

Professor Wagner has made extensive analytical and experimental investigations into the whole of this subject (Refs. 7, 8, 9, 10). An independent check on parts of the theory has been made by Dr. Mathar (Ref. 11), while an excellent summary of the formulæ with explanatory notes is given in Ref. 12.

It is claimed that the construction can be used to advantage in cases where the ratio

$$\frac{\sqrt{\text{Shear load in lbs.}}}{\text{Depth of girder in inches}}$$

is less than seven, and if the ratio exceeds eleven a shear-resistant plate web

girder (*i.e.*, a girder that does not normally buckle diagonally under load) is preferable.

Obviously the behaviour of thin sheet web girders of this type is largely dependent on the stiffness of the bounding members to which the web is attached, and in the case of a beam of the type shown in Fig. 1, App. III, such stiffness is obtained through the use of numerous verticals, the limits for the spacing of which is given as one-half to one-sixth the depth of the girder. The effect on the girder stiffness due to variation in spacing of verticals is clearly shown in Ref. 11, as is also the variation in number and angle of waves for different pitching of verticals.

Professor Wagner shows that, under the proper conditions, the web in a rectangular panel buckles into waves inclined at very nearly 40° to the horizontal (Ref. 9, page 22). In routine design work, however, it is probably sufficiently accurate to take the wave angle α as 45° where vertical stiffeners are used.

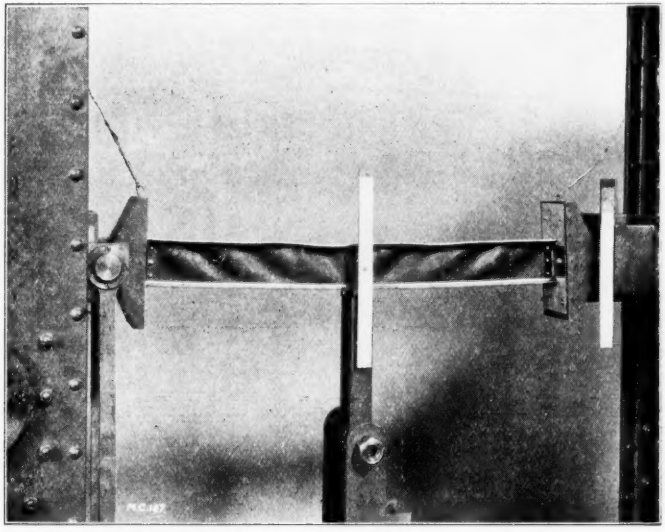


FIG. 6.

Sheet-web spar. Stiffeners widely spaced.

The above-mentioned experiments by Dr. Mathar (Ref. 11) show clearly that it is advantageous not only to secure the verticals to the web but also to gusset them to the spar booms.

In many cases very close agreement has been obtained between the results of calculations based on the Wagner theory and laboratory experiment. As Prof. Wagner says, calculated and measured stresses should tend more and more towards the same values as failing loads are approached, since the waved form is then very definite, and consequently the main assumption on which the theory is based, *i.e.*, negligible flexural stiffness of the sheet, is more closely realised than for small loads where for many parts (*e.g.*, external surfaces) it is essential that the waved form should not be present under normal loads.

For these reasons, among others, it will probably be thought advisable to check the strength of structures where construction is based on formulæ given in the third appendix. Apart from checking the theory against a particular construction, tests are necessary as a means of determining the suitability of

the details of the construction in regard to such matters as development of the desired stresses, strength of fastenings, etc.

The necessary experiments can usually be made in a simple manner. Fig. 6 illustrates a test on a wing spar, the spacing of the verticals was rather wide and that resulted in deformation of the booms—an effect which is clearly seen in the photograph. Fig. 7 shows another test in progress, notice that the spacing of the web stiffeners is about right, having regard to the pull in the web and the stiffness of the boom.

As to the weights of girders designed according to these principles. Such comparisons between lattice and sheet web girders of similar overall dimensions as I have been able to make has afforded a check on the ratio quoted above.

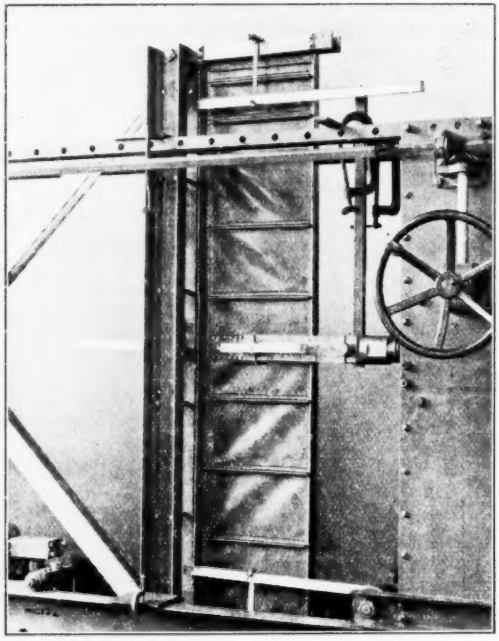


FIG. 7.
Sheet-web spar. Correctly spaced stiffeners.

When, however, this ratio becomes less than two, limiting condition of minimum practicable thickness of sheet makes itself felt; on that account for really small shear loads, the lattice girder may show to advantage in the matter of weight so far as the web portion only is concerned.

Stabilisation of Spar Booms

The web member, however, performs another duty in addition to resisting shear loads, in that it assists the sheet covering in stabilising the spar booms.

The conditions under which there is "assisted" stabilisation of a strut member by means of two sheets of material roughly at right angles is, I consider, one of the most important matters in aeronautical structural engineering at the present time.

Fig. 8 shows an example of this type of construction consisting of the upper and lower booms of a spar connected together by a single sheet of light alloy (web member) each supported by a second sheet (wing covering) in planes approximately at right angles to the web sheet. These covering sheets also act as closing members and edge stabilisers for the spar boom channel edges. In this construction the stress developed in one boom, under the compressive forces shown, was about three times that of the boom unsupported, and about twice that of the boom elastically supported by the covering only. Pure strut action may be nearly eliminated by these means and the stresses developed may approximate to the yield strength of the material in the booms; thus steel shows up to advantage in such constructions.

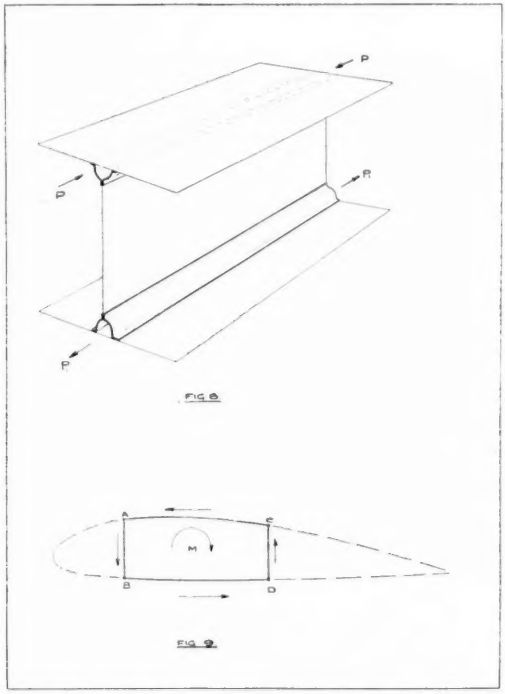


FIG. 8. *Spar booms, each stabilised by two sheets at right angles.*
FIG. 9. *Method of resisting torsion in box wing.*

Torsional Stiffness of Metal-covered Wings

Although the use of sheet metal previously described is important, an equally important effect from the use of rigid wing covering for monoplanes is the resulting large degree of torsional stiffness. It is easy to see why that should be so. If the covering is not stiff and if no internal anti-torsion devices are used, then the torsion is resisted by the differential bending of the spars; clearly stiffness achieved by such means can be obtained only at the expense of extra weight. If spars having a measure of torsional stiffness are connected by a stiff rib at their extremities, then the total torsional stiffness of the wing is

$$T_F + T_R + T_B \text{ (Ref. 13).}$$

These quantities are proportional to the polar moments of inertia of the front and rear spars and to the resistance to torsion by differential bending respectively. Evidently the polar moment of inertia of the complete box wing is considerably the greater; a similar remark is true in respect of any practicable *internal* anti-torsion device.

In such a wing the torsion is taken in the manner indicated in Fig. 9.

The member A acts as the upper boom for spar AB, also as a boom for the "horizontal" spar AC, the web of which is the curved skin covering, the second boom being also the upper boom for the rear spar; thus, in effect, each main longitudinal serves the dual purpose of boom for two beams, each in a plane roughly at right angles to the other.

There are several methods of estimating the loads in these members in the case of a wing under torsion (see Ref. 14), of these the method involving

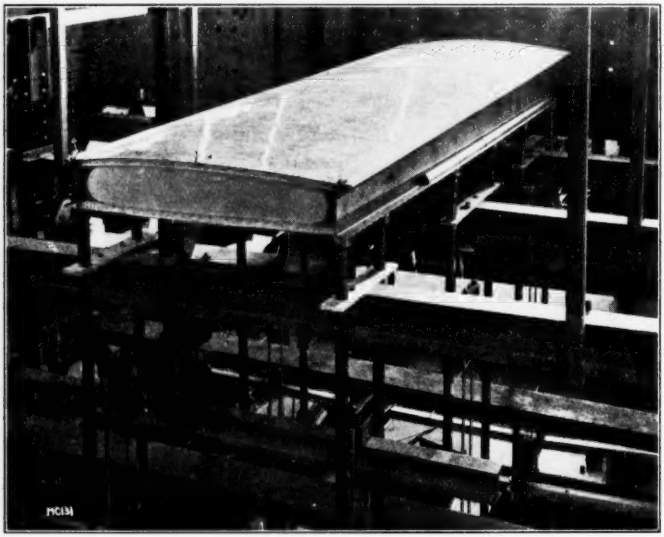


FIG. 10.

"Box" wing under test.

the use of Batho's formula is the best. The end loads are smaller, taking account of the four booms, than in the case of the differential bending of separate spars, since any boom in the torsion case is subjected to two forces of opposite sign, *e.g.*, if a positive load arises from the forces in the spar proper then a negative load is induced by the pull in the skin or vice-versa.

The stresses in spar webs can be estimated by Wagnerian or other methods, and appropriate sizes allocated, but with the skin the case is different since that part of the structure is subjected to both shear and longitudinal forces. This case of loading of metal webs has not, so far as I am aware, been the subject of any analytical investigation. The problem has been investigated experimentally (Ref. 11), and it is there shown, as indeed one would expect, that the waving is modified when a direct force is applied in addition to the shear force. Waving of the outer skin affects drag and therefore is of far greater importance than is the waving of the internal webs of the spars. Since no means exist of estimating the critical stress of a skin so loaded, the matter must be determined by experi-

ment. Fig. 10 shows a wing under test, the best arrangement of covering reinforcement being one of the matters under investigation. There are other forces such as direct drag and diaphragm effects which cannot be reproduced in a simple test. Thus the skin must be a little thicker and the reinforcement placed closer than would appear necessary from such an experiment as the one shown. In this instance two spars are used. Incidentally here, the use of a rigid skin with two or more girders of this type could be termed a " single spar " construction for the reason that if all the load is concentrated on one girder only there is little difference between the deflection at the tip of that component and the deflection at the end or ends of the unloaded girder or girders. We will, however, consider each girder as a spar and in that way regard Fig. 10 as a two-spar wing.

Multi-Spar Wings

Whether it is necessary to have more than two such spars in a wing depends on size and loading, but other matters have to be considered before arriving at a decision on the number.

Broadly, the considerations are economic distribution of material and cost. For example, if in the case of a large aircraft with a high loading, only two spars are proposed, difficulties will arise in regard to the fabrication of the large volume of material required in the compression booms, and the material may have to be of relatively low yield strength. The centres of area of the booms will necessarily be at a greater distance from the wing surface than would be the case with smaller booms and difficulties may be encountered in developing high stresses arising, for example, from the use of long rivets, etc., required for the assembly of a number of thick plates into built-up sections.

Again, if not more than two widely spaced spars are used the advantage that would arise from the structural use of the deeper portions of the aerofoil is lost, also large areas of sheet covering would need secondary support, and such support would not in general contribute to the moment of resistance of the wing. The difficulty can be countered by placing the spars closer together, but not so close as to necessitate the use of wide overhanging leading and trailing portions, moreover, as the " structural box " is reduced in overall dimensions, the torsional stiffness is also diminished, thus the use of several spars necessitates the utilisation of a considerable width of the aerofoil for structural purposes and as a direct consequence the wing is given maximum torsional stiffness. Further, the advantage that arises from a multi-spar system of wing design is very real in so far as the utilisation of the deeper parts of the aerofoil is concerned; the rigidity that accompanies the use of a stressed skin allows of the employment of the use of simple methods of calculating the loads induced by torsion on the spars; thus the direct forces can be distributed arbitrarily, the moments of inertia of the spars being selected to give a predetermined flexural axis; in applying this method the deeper spars can be designed to carry greater loads than the shallower ones. A method (Burgess) of estimating the forces in the separate members of a multi-spar wing due to the torsion, will be found in Ref. 14 quoted in connection with Fig. 9. The loads arising from the direct load and torsion calculated separately can then be added algebraically.

It is clear from the foregoing that precise answers to questions relating to numbers and spacings of spars must for the present not be expected, and that it is likely to be some time before the optimum number for any particular case will be postulated. Whilst economies in weight at the root of a large wing may be made by the use of a number of spars, yet this entails the employment of a lot of minimum thickness low stressed material from a point near, say, mid-span outwards to the wing tip. Many other considerations could be raised, but enough has been said to show that experience is likely to play the greater part in giving the final answer to the many issues involved.

Finally, in regard to the wing illustrated, it may at first sight be argued that there is nothing substantially new in this box-like construction as wings of apparently similar design have been on view at aeronautical exhibitions and have been described in various publications. Perhaps what I have just said may help to dispel that idea; structures of the same general shape have certainly been exhibited, but closer comparisons will reveal differences and, further, that there are enough variables in the construction to keep the problem new for some years to come.

As to structure weights for the construction shown, all that can be said at present is that when we have chosen the most favourable material and placed it most favourably for giving strength and stiffness then we have done all that can be done to obtain the minimum possible weight. The principles I have outlined certainly show the way. An idea of what is to be gained as regards spar weights is shown in Fig. 11, the two aircraft concerned being very nearly

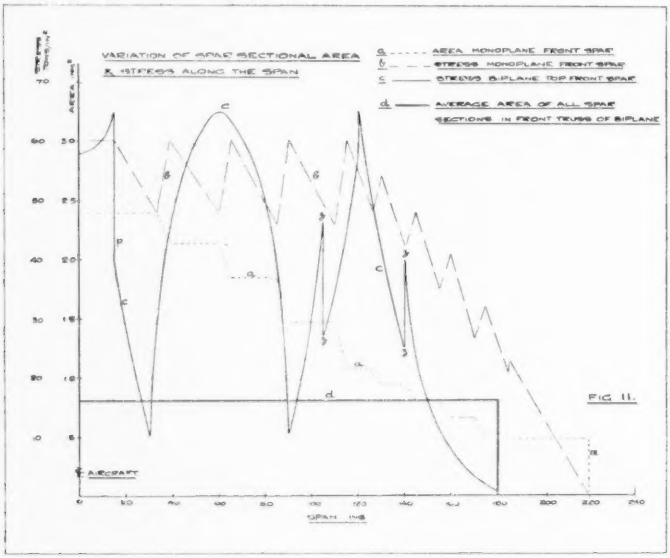

VARIATION OF SPAR SECTIONAL AREA
& STRESS ALONG THE SPAN
a AREA MONOPLANE FRONT SPAR
b STRESS MONOPLANE FRONT SPAR
c STRESS BIPLANE TOP FRONT SPAR
d AVERAGE AREA OF ALL SPAR SECTIONS IN FRONT TRUSS OF BIPLANE
FIG. 11.
SPAN ins

FIG. 11.

Sectional area and stress curves for monoplane and biplane spars plotted against span.

the same weight and designed to the same load factors. The variations in sectional area along the length of a monoplane front spar are shown in curve *a*, while the stresses along the boom for one condition of flight are shown in curve *b*. Curve *c* shows the variation in stress along the length of the top front spar of a biplane wing, while curve *d* gives the average sectional area of the front top and bottom wing spars taken together as a single spar. The *variation* of sectional area of this virtual combination of spars cannot be shown conveniently in the diagram, but the variations in area of the top front spar in regions of high stress can be clearly distinguished at points *z*, *z*, etc., on the stress curve *b*. Due to the fixity at the point *p*, where the centre section and outer wing spars join, together with the lamination, the stress distribution shown is good for a single bay biplane wing spar, but even if improvement could be obtained by modification to the detail design, the construction of a biplane

spar member having the uniformity of stress indicated in curve *b* is not a feasible proposition.

Only in really large biplane constructions would such refinements in design be possible, whereas no difficulty exists in getting the uniformity of stress shown in curve *b*, in monoplane constructions as described. At the moment we cannot proceed further than a simple monoplane wing; the word simple is perhaps a misnomer here, the calculations may, in a casual manner, be regarded as simple in comparison with what is required for a biplane structure. In the case of the monoplane, however, flutter and allied investigations become of prime importance and the additional calculations connected therewith make the matter more involved and complicated than it might at first sight appear.

Another form of wing construction in which the whole skin or a large part of it is reinforced against considerable longitudinal forces is worth attention; in this the bending is resisted by a reinforcing combination and not by the booms of separate and distinct spars. Corrugated internal plate attached to a plain outer skin would appear to be the best arrangement, graduation in area against the variation in load could well be executed through the use of lamination in the flat skin. There are certain manufacturing difficulties, however, which so far have precluded an experimental investigation of this construction. The main difficulty, which has been excessive riveting is, however, likely to be overcome in the near future.

Manufacture

As to questions of manufacture and materials, after a few remarks on methods of construction it is appropriate that the paper should conclude with a brief review of materials.

In general, panel beating on a large scale can be avoided by the use of developable surfaces, and by careful selection of shape of sheeting; the use of laid-on flat sheet can be supplemented by putting in small pressed parts, the production of which is, or may be, cheap.

So long as a rolling mill or draw bench is available the manufacture of stringers is a particularly cheap operation, but the manufacture of hoops can be troublesome in the early stages; considerable scope for ingenuity is offered in working these to sharp contours.

The stringers and hoops should be continuous, the hoop being deeper than the stringer (therein lie chiefly the difficulties of manufacture of these parts), a hole being cut in the former to allow of the uninterrupted passage of the stringers; no connection need be made between the hoops and stringers other than through the medium of the skin. The use of relatively stiff hoops (although troublesome if bending is to be the operation for obtaining transverse shape of the fuselage) has one real advantage, that being the assembly of the complete structure " segmentally." The hoops are divided into appropriate sections, and the sheets lightly secured to these pieces while in a jig. The whole segment (possibly a complete half of the structure) can then be removed from the jig and the rivets " power-driven." Thus in the case of a small fuselage only two lines of rivets need to be secured by ordinary and usually relatively expensive methods.

Riveting, remains the most expensive item, and every effort should be made to reduce it. For example, a system of internal framework requiring only single rows of rivets for attaching the skin involves a minimum of costs in assembling and there is, at the same time, a negligible decrease in strength and stiffness. " Open stiffeners " have such advantages over closed sections as ease of inspection, facilities for the attachment of fittings, and less likelihood of hidden corrosion; these are advantages which cannot lightly be discarded.

Design of fittings through which large local loads are to be transferred to the shell is cited as one of the major difficulties of stressed skin constructions. Such difficulties are, however, more apparent than real, and no trouble need

be experienced if the fittings are used in conjunction with stiff bulkheads, from which at the places of attachment, additional short lengths of stringers are added and where necessary reinforcing laminations are put in. The design of ships' hulls may be studied with advantage in this connection.

Materials—Welding

Under this sub-heading are introduced one or two considerations connected with spars used in ordinary girder constructions. Firstly, as to the avoidance of riveting, a continuous search for a means of reducing or even eliminating, the process has brought to the fore the question of electric spot or roller welding. These practices have long been in use in general engineering, but their adoption by aircraft manufacturers has been slow. Two causes have operated as deterrents, the first being the scarcity of suitable materials which, after welding and without subsequent heat treatment, have the mechanical properties requisite for aircraft structures, and the second, the absence of fool-proof welding machines. Several makes of suitable welding machine are, however, now available. Ordinary snap-headed rivets on wing surfaces have an appreciable adverse

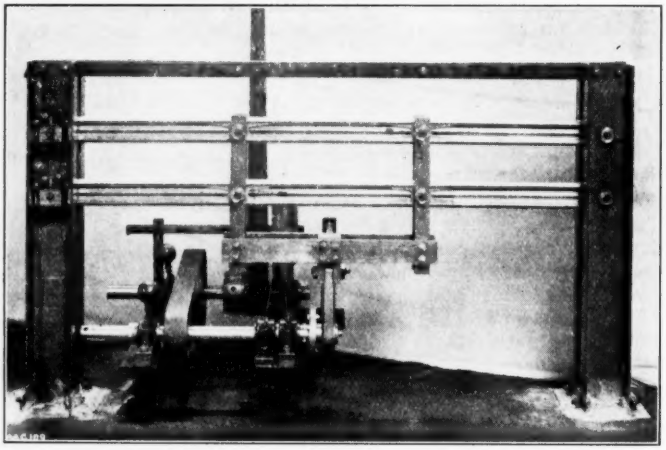


FIG. 12.
Fatigue tests on spars.

effect on the total drag, particularly when used near the leading edge (Ref. 15). Flush or nearly flush riveting is very desirable in this case. The use of resistance welding makes an obvious appeal in this connection. As to the difficulty about materials, while there is every likelihood that a structural material, having the necessary mechanical properties, will eventually be produced which does not require heat treatment after welding, that objective has not yet, so far at any rate as steels are concerned, been attained.

Steels

This matter has been examined in Bristol in connection with steel spars and Fig. 12 shows such parts in a machine ready for a vibration test. Several materials have been tried and compared with riveted spars in similar materials vibrated under the same conditions; the difference in length of life was enormous in all cases, and although the conditions of vibration are such as may not occur on an aircraft, yet the superiority of the riveted joint rules the other methods

out of court except for non-structural parts and perhaps lightly stressed members such, for example, as a hull or monocoque fuselage, assuming in these cases that the reduction in manufacturing costs justifies the inevitable increase in structure weight over the use of riveted light alloy sheet construction.

The only thing to do with steels as they are now is to heat-treat after welding, and this is being done very effectively by Messrs. A. V. Roe, of Newton Heath. The corrugated components of the Ni-Cr steel spars are assembled by roller welding, the complete member is then heat-treated by the electric resistance method. It would appear that this combination of operations is going to offer a strong challenge in the matter of cost to other forms of steel spar manufacture. Of course, this process is limited to spars and similar type components of girder constructions. The heat-treatment of a complete shell construction is

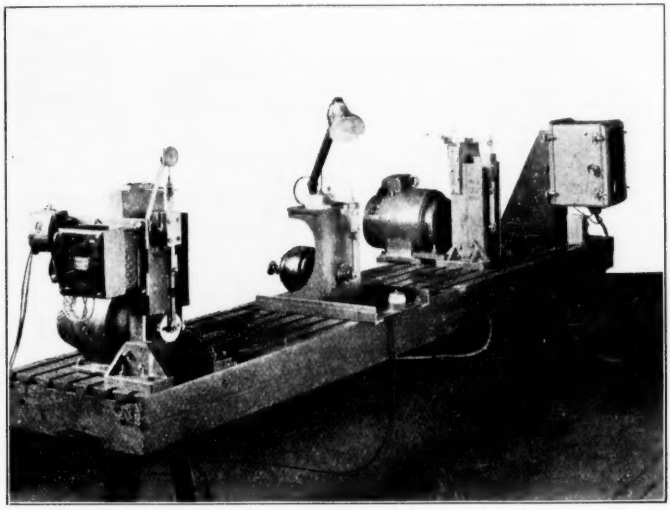


FIG. 13.

Fatigue experiments on pairs of strips joined by electric spot welding or riveting.

out of the question, individual welds must be left untreated, at any rate, at present.

In regard to structures assembled by welding, it appears certain that the process will endure for certain classes of aircraft. Different methods of welding are available and as far as can be ascertained, equally good welds can be obtained by all methods. The recently discovered atomic hydrogen method developed by Metropolitan Vickers appears, however, to have definite advantages over oxy-acetylene welding, in as much as carburisation or oxidation of the weld cannot take place. Briefly, the method consists of blowing a stream of hydrogen gas through an electric arc that is struck between tungsten electrodes; the high temperature of the arc completely dissociates the mass of gas in contact with it into the atomic state. This atomic hydrogen diffuses rapidly from the arc cone to the cooler regions where it recombines into the molecular state. In so doing the hydrogen gives up the energy which has previously been absorbed from the arc. There is therefore an extremely hot flame of a single gas without the presence of the oxygen usual in other welding flames.

The necessary technique is easily acquired by operators and due to the heat

in the zone of the electrodes, which approaches 4,000°C., the speed of welding is probably about four times that of oxy-acetylene welding.

Light Alloys

In regard to light alloys for stressed skin constructions, there is no question of heat-treatment subsequent to welding and without such heat-treatment consistently reliable welds in these materials seemed improbable until an aluminium rich Mg-Mn alloy, known as 4S was tried. This alloy is made to Air Ministry specification D.T.D. 209. A long series of fatigue tests has shown it to be most consistent so far as welding is concerned. The method of testing is shown in Fig. 13. The welds are subjected to shear, the outer fibres of the test pieces having to resist alternating longitudinal forces arising from bending. A series of S/N curves obtained by testing various materials is shown in Fig. 14. The consistency of the 4S is most notable.

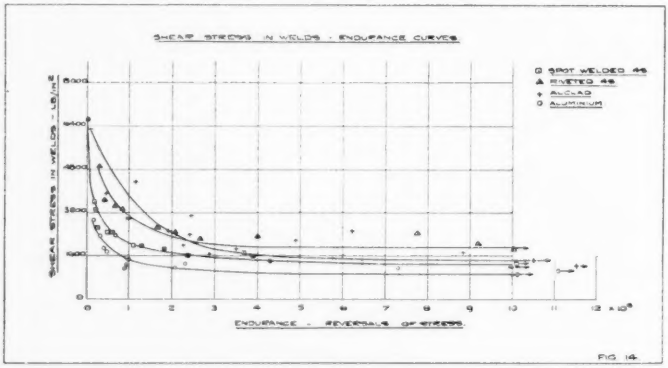


FIG. 14.
Curves showing relation between fatigue shear stress and endurance.

Other investigations on this matter are in progress and if the general test results are consistent with the first tests, then progress on research of structures of the type dealt with will be greatly accelerated and ultimately the cost of monocoque constructions should be substantially less than can possibly be the case with shell type constructions assembled by riveting.

The mechanical properties of 4S are not at the present time very widely known, but by the courtesy of the Northern Aluminium Company I am able to show in the following table these properties for the material in the five states in which it is made.

PHYSICAL TESTS ON 4S SHEET MATERIAL.

	Gauge.	Yield Stress tons/sq. in.	0.1 % Proof Stress tons sq. in.	0.5 % Proof Stress tons sq. in.	Max. Stress tons/sq. in.	Elongation % on 2in.
4SO	.040	4.87	8.1	8.75	12.5	16.0
4S$\frac{1}{4}$H	.022	11.1	12.75	13.4	13.95	4.0
	.036	—	12.45	13.5	14.15	6.0
	.064	12.95	13.3	13.4	14.05	6.0
4S$\frac{1}{2}$H	.018	11.9	13.3	14.7	15.5	4.0
4S$\frac{3}{4}$H	.018	13.3	14.70	15.5	16.3	3.5
	.048	15.6	16.25	17.2	17.65	4.0
4SH	.016	13.7	15.8	17.3	17.8	3.0
	.064	16.9	17.55	19.0	19.1	3.0
	.048	—	15.7	16.9	17.9	5.5

$E = 4{,}400$ tons per sq. inch.

As to magnesium-rich alloys, one does not care to forecast what the ultimate uses of such alloys will be. Use of the material is now being made for cowling and fairing, while non-structural parts, such as chairs, etc., in civil machines, are made from magnesium alloy. The alloys have not yet, however, been used to any extent in primary or even secondary structure; perhaps the necessary application of heat required during forming operations and fear of corrosion, and rather low intrinsic stiffness have most to do with this. Great strides have been made in regard to the anti-corrosion problem, consequently the use of the material as covering for, say, monocoque fuselages, demands serious attention—bearing in mind the fundamental requirement of low absolute density of a material used in panel form.

Corrosion

The matter of corrosion cannot very well be omitted, particularly when the metal is in direct contact with the atmosphere. During the whole of the time of the development of metal aircraft, designers of landplane structures have not been troubled by the corrosion bugbear to anything like the extent that was predicted in the early days.

Ordinary simple precautions in regard to the removal of dirt and grease from surfaces followed by stove enamelling in the case of steel and anodic treatment for aluminium alloys, does all that is necessary; where Alclad is used, a coat of varnish only is required. Enamel is not suitable for steel parts machined to fine limits, nuts and bolts, etc., and in such cases cadmium plating is recommended.

If such protection is considered inadequate, then non-corrodible or corrosion-resistant materials are to hand for every steel structural aircraft part, not excluding such parts as stranded cable. This subject is dealt with in Ref. 16; the number of specifications has more recently been considerably augmented. No appreciable increase in weight or decrease in strength is incurred by the use of these corrosion-resistant materials, the latter in many cases, indeed, being stronger than " equivalent " materials ordinarily used. Steels of the " Two-score " type are best suited for main structure members made from strip, while fairly high carbon content stainless iron appears at the moment best suited for solid drawn tubes. These materials are not, however, completely corrosion-resistant, and for marine craft I believe it is the practice to use varnish or enamel. If, however, the greatest possible immunity from corrosion is specified, then the austenitic steels must be employed, and, as the .1 per cent. proof stress ought not to exceed 40 tons per square inch, some increase in weight is incurred if main members are constructed of such steels.

Austenitic sheets are, however, widely used for fittings even on landplanes. This use is probably due to the above strength figure, which is high enough for such parts, and to the fact that heat-treatment is not required after manufacture.

As to the light alloys, the use of the highly corrosion-resistant material Alclad is strongly recommended. So far as landplanes are concerned, it is evident that ordinary precautions reduce corrosion to a minor trouble, and no further comment is necessary.

General Remarks—N.A.C.A. References—Acknowledgments

It will be realised that this paper has been written primarily for engineers who have not delved very fully into the question of stressed-skin bodies, and judging by conversations with others employed in the industry in different parts of the country, and also from the output of such structures compared with the total output of fabric-faired girder constructions, they appear to be a considerable majority of those employed on design.

The information available is very scattered, and the paper is an attempt—I hope successful as far as it goes—to make a connected story covering as much ground as time permits and bringing in such experience as I have on the subject.

It would be foolish to prophesy without experience of sheet construction under prolonged flying conditions; we have not got that in this country; there is no doubt that steady progress is being made all over the world with stressed-skin construction, whilst fabric-faired girder designs are diminishing. The reason why the matter has been treated in such an apathetic manner in this country is due, I believe, to lack of data and the formidable amount of testing necessary when making a beginning with the construction. While calculation of the strength of these structures generally is impossible by mathematical methods, yet one feels sure that design formulæ will eventually be evolved from the experimental data that is being accumulated.

However that may be, one can only associate mass production aviation with a construction that lends itself primarily to mass production of aircraft; a construction that will weather safely outside storage, a construction in which low parasitic drag goes hand in hand with low structure weight, and, above all, a construction which will, on every count, prove the safest to offer to the public at large as a means of transport. When all these qualities have been embodied in a particular type of aircraft, there will, I consider, if it otherwise meets the needs of the times, be no doubt about its success.

On turning to the list of references, it will be noticed that five reports cited in connection with the design of Wagner beams are American translations of the German works, while the sixth is also a N.A.C.A. Technical Note. Other N.A.C.A. Reports or Notes will also be found in the list. I am able to quote these references by the courtesy of Mr. John Jay Ide; he asked me to make it clear, however, that these documents can be consulted in the library of the Royal Aeronautical Society in London, and that he will not be able to meet requests for copies of these reports. Anticipating that some members of the Society who are interested in the matter may not be able to get hold of the library copies just when they want them, I have put certain of the principal Wagner formulæ into Appendix III.

Finally, I have to thank the Directors of the Bristol Aeroplane Company for allowing me to write a paper based mainly on experience gained while in their employ, also I thank the Director of Scientific Research, Air Ministry, for permission to use photographs obtained during the execution of work carried out on his behalf.

Appendix I.

Critical Stresses of Thin Curved and Flat Plates

The formula derived by Redshaw for the critical buckling stress for a curved panel axially loaded and simply supported at axial and circumferential edges is

$$p = \{ E/6(1-\sigma^2) \}^{\frac{1}{2}} \{ \sqrt{[12(1-\sigma^2)t^2/r^2 + \pi^4 t^4/b^4]} + \pi^2 t^2/b^2 \} \quad . \quad (1)$$

σ = Poisson's ratio,
b = length of arc,

the other symbols having the meaning allocated in other parts of the paper.

If $(b/t)^2$ is large in comparison with r/t the formula reduces to that obtained for the complete tube (see references in table below)

$$p = \sqrt{\{ 1/3(1-\sigma^2) \}} E(t/r) \quad . \quad . \quad . \quad . \quad (2)$$

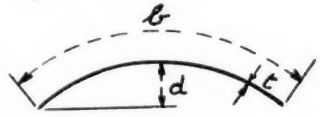
so that if the angle subtended by the panel is fairly large the critical stress is dependent only upon the curvature and thickness and not upon the length b.

If the angle is small, the above formula should be amended to

$$p = \sqrt{\{ 1/3(1-\sigma^2) \}} E(t/r) F_1 \quad . \quad . \quad . \quad . \quad (3)$$

where $F_1 = 1 + D\,(t/d) + \frac{1}{2}\,(Dt/d)^2 + \ldots +$
$D = \pi^2/8\sqrt{\{\,12\,(1-\sigma^2)\,\}} = 0.368$

$d = r\phi^2/8 =$ " the bulge "



$\phi =$ angle subtended by arc of panel.

If $(b/t)^2$ is small in comparison with r/t the formula reduces to that for a flat panel

$$p = [\pi^2/\{\,3\,(1-\sigma^2)\,\}]\,E\,(t/b)^2 \quad . \quad . \quad . \quad (4)$$

For slightly curved surfaces equation (4) must be modified to

$$p = \{\,\pi^2/3\,(1-\sigma^2)\,\}\,E\,(t/b)^2\,F_2 \quad . \quad . \quad . \quad . \quad (5)$$

where $F_2 = [\,1 + \sqrt{\{\,1 + 7{\cdot}4\,(d/t)^2\,\}}\,]/2.$

For slightly curved panels it is advisable to use formula (3), although the critical stress will be the same if formula (5) is used.

The graph shows the relationship between the multiplying factors F_1 and F_2 and the d/t ratios.

It is stated in the text of the paper that the theoretical critical stress given by formula (3) above was in many cases 80-90 per cent. of the collapsing load of some actual tests; in this connection it must be remembered that the critical stress is the stress at which instability will occur, but that it is possible for a test specimen to take additional loads after the critical stress has been reached.

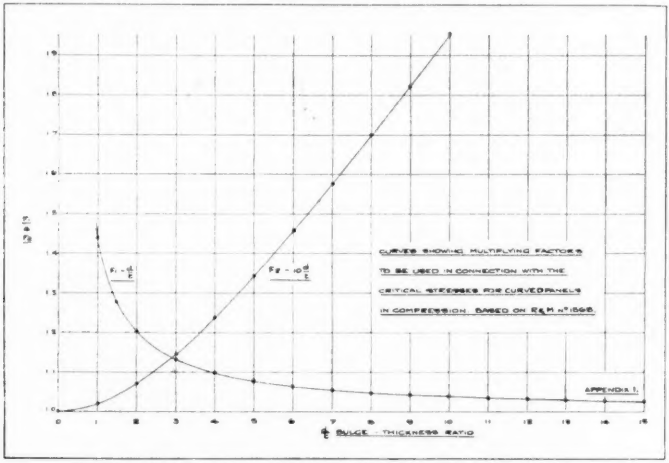

CURVES SHOWING MULTIPLYING FACTORS
TO BE USED IN CONNECTION WITH THE
CRITICAL STRESSES FOR CURVED PANELS
IN COMPRESSION. BASED ON R&M N°1556
APPENDIX I.
d/t BULGE - THICKNESS RATIO

FIG. 1.

There is generally a discrepancy between the theoretical and actual critical stresses for most cases of instability; this is mainly due to the difficulty in reproducing the exact theoretical boundary conditions on the specimens. Another cause which is often overlooked is that in most cases the formulæ are only valid providing the limit of proportionality is not exceeded. The question of *plastic instability* is of importance in certain phases of structural design and has, as yet, received little consideration.

In addition to the foregoing case, the table below shows, with references, the problems relating to critical instability that are known to me to have been solved.

		Reference.
(1) Plane Panels Shear	$KE\,(t/b)^2$	17
(2) Plane Panels Compression ...	$KE\,(t/b)^2$	18
(3) Curved Panels Shear	$KE\,t/r$	19
(4) Tubes, Torsion	$KE\,(t/r)^{1\cdot35}$ (Empiric) ...	20
(5) Tubes, Compression	$KE\,t/r$	21
(6) Segment of Tube Compression...	$KE\,t/r$ ... R. & M.	1565
(7) Corrugated Panels Shear ...	$KE\,(t/b)^2$	22
(8) Corrugated Panels Compression	$KE\,(t/b)^2$	23

Appendix II.

Effect of Holes on Strength of Panel Bracing

The necessity for the investigation of the case of lightened and reinforced plates subjected to shear forces is, at present, of more urgency than the case of similar plates subjected to end load. Unlike the former case, an approximate estimate of the strength of the latter can be made.

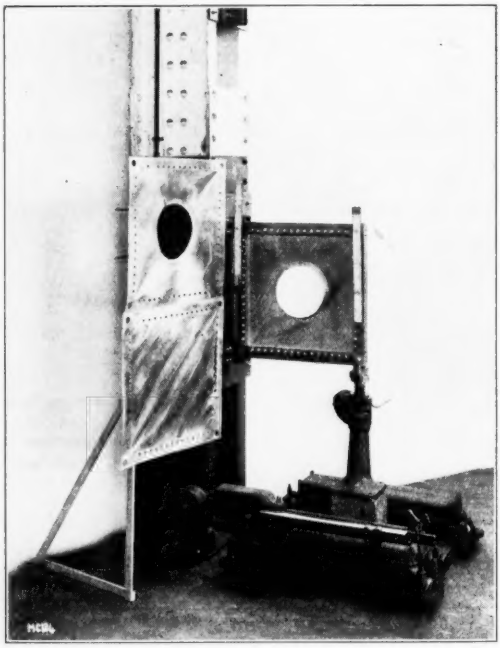


Fig. 1.

Method of Test. Square sheets in shear.

The purpose of this investigation is to find by how much strength and stiffness of panels in shear are reduced by cutting holes in them, and to find what forms of stiffening will restore the maximum elastic strength and stiffness for a minimum expenditure of weight.

The first part of the investigation was confined to square panels with circular holes cut in them, and the method of test is as shown in Fig. 1.

A square panel is secured to rigid bars freely pivoted at their ends. The pin centres are 22in. apart, and the material is Alclad 0.022in. thick.

Panels tested to date are as follows:—

(1) Plane sheet.
(2) Sheet with 6in. dia. hole (unbeaded edge).
(2) ,, ,, 9in. ,, ,, ,, ,,
(3) ,, ,, 9in. ,, ,, (weight of beading equal to weight of metal removed for hole).
(4) ,, ,, ,, ,, ,, vertical stiffeners.
(5) ,, ,, ,, ,, ,, vertical and horizontal stiffeners.
(6) ,, ,, ,, ,, ,, two laminated rings each side.
(7) ,, ,, ,, ,, ,, four laminated rings each side.

All the panels except No. 7, are shown in Fig. 2. The results shown plotted against shear load in the graph, Fig. 3, are deflections measured at and parallel to the direction of loading.

The investigation has not proceeded far enough to allow of the drawing of final conclusions. Two matters, however, are worthy of comment.

The sudden fall in stiffness indicated at points x, x, etc., on the curves cannot be associated with any observable phenomenon on the panel while being loaded, *e.g.*, appearance of tension waves or their permanence.

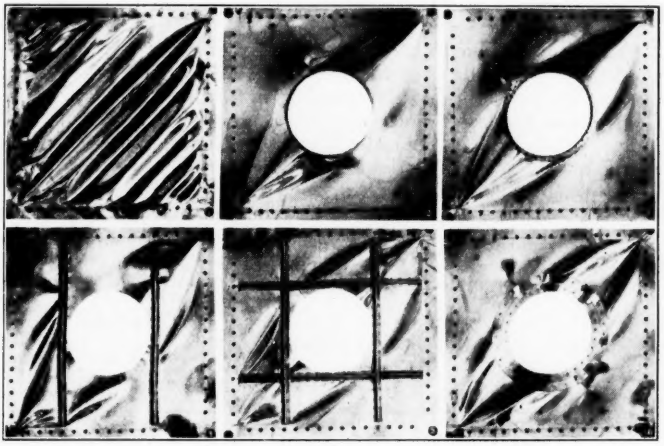


FIG. 2.
Sequence of sheets tested. Types of failure.

From the aspect of restoring the greatest percentage of the original ultimate strength, the most effective type of stiffening weight for weight is laminated plates. As might be expected, the use of sectioned stiffeners (panel five, Fig. 2) results in greater stiffness over the first range of load, and this type of stiffening also gave the greatest elastic strength. The amount of elastic strength for these panels is not apparent from the curves shown in Fig. 3. This is an extremely important design consideration, the determination of the true elastic strength necessitating the use of elaborate strain measuring apparatus.

Other forms of stiffening are being tested, and subsequently the investigation is to be extended to holes of various diameters and forms, and then to the case of lightened plates under combined end thrust and shear force.

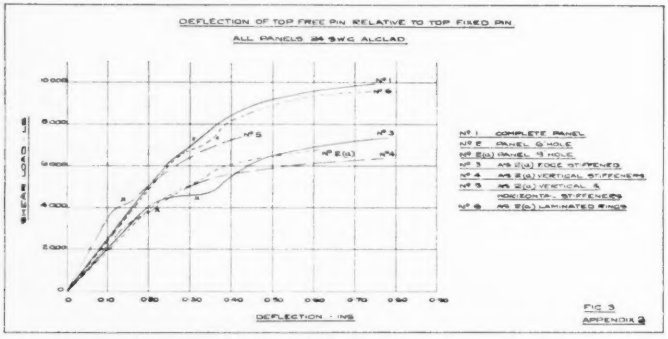

DEFLECTION OF TOP FREE PIN RELATIVE TO TOP FIXED PIN
ALL PANELS 24 S.W.G. ALCLAD
SHEAR LOAD - LB
DEFLECTION - INS
FIG 3
APPENDIX 2

FIG. 3.

Graphs showing relation between load and relative displacement of scales shown in Fig. 1, *App. II.*

APPENDIX III.

Theory of Webs of Girders

The following notes and formulæ should be read in conjunction with the relevant part of the paper:—

f = Tension in the web in stress units.
H_t = Load in tension boom in force units.
H_c = Load in compression boom in force units.
α = Angle of waves to horizontal.
V = Load in vertical members in force units.

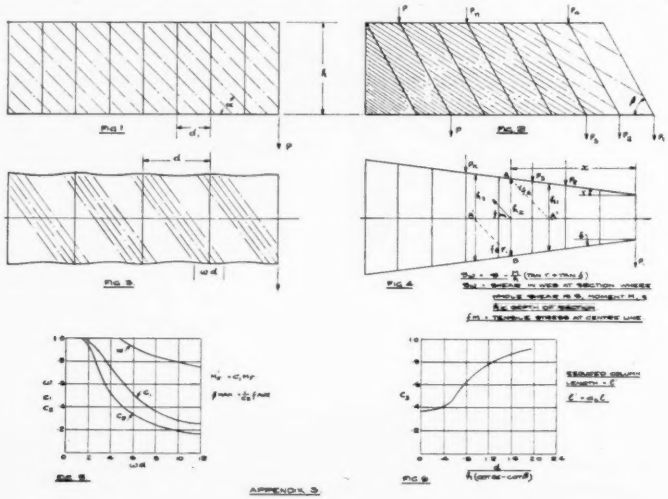
Other symbols shown in Fig. 1.

$$f = 2P/ht \sin 2\alpha = 2P/ht \quad (\text{for } \alpha = 45^\circ) \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$H_{t,c} = \pm Px/h - (P/2)\cot\alpha = Px/h - (\tfrac{1}{2})P \quad (\text{for } \alpha = 45^\circ) \quad . \quad . \quad (2)$$

$$V = -P(d/h)\tan\alpha = -P(d/h) \quad (\text{for } \alpha = 45^\circ) \quad . \quad . \quad . \quad . \quad (3)$$

It is stated (Ref. 10, page 1) that when the load acts in one direction only or to a much greater amount in one than in the opposite direction, it pays to



put the stiffeners at about 30° to the vertical; it is proved that the weight of the sheet web is lowered 15 per cent. and the stiffness is raised 55 per cent. by such means. The formulæ for these cases follow, although it frequently happens that the external forces act for different cases in opposite directions, the total force in one direction not being greatly different from the total force in the opposite direction, thus the angle β (Fig. 2) for general use should be taken as 90°.

The following formulæ apply, however, for any angle β, and cover the case of the stiffeners or struts (the words are used interchangeably though stiffener is probably the more appropriate) secured to the web.

$$f=(2S/ht)\ \{\ 1/\sin 2\alpha\ (1-\tan\alpha\cot\beta)\ \} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

$$H_{TC}=\pm M/h-S/2\ (\cot\alpha\pm\cot\beta) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

$$V_1=-[(S_L+S_R)/2]\ (d/h)\ (\tan\alpha/\sin\beta)\ \{\ 1/(1-\tan\alpha\cot\beta)\ \}\pm Pn/\sin\beta \quad (6)$$

$$V_2=-[(S_L+S_R)/2]\ (d/h)\ (\tan\alpha/\sin\beta)\ \{\ 1/(1-\tan\alpha\cot\beta)\ \} \quad . \quad . \quad (7)$$

S = Total shear force at section considered.
M = Moment at section considered.
S_L = Shear to left of the strut under consideration.
S_R = Shear to right of the strut under consideration.
Pn = External load at the strut under consideration.

Other symbols have the meaning previously allocated or as shown in Fig. 2. Providing the spacing of the struts is not outside the limits one-half to one-sixth of the beam depth, the angle α is approximately equal to $\beta/2$.

Since the angle β will in general be 90° the formulæ reduce to:—

$$f=2S/ht \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

$$H_{TC}=\pm M/h-S/2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

$$V_n=-[(S_L+S_R)/2]\ (d/h)\pm Pn/2 \quad . \quad . \quad . \quad (10)$$

P_n = the external force applied at the strut V_n.

In the relevant references, formulæ covering the case of beams having struts flexible in the plane of the web sheets are quoted. In general, however, it is preferable to secure the struts to the sheet, thus securing the greatest rigidity, the proportionate increase in the strength of the struts obtained by this means is indicated below (Fig. 6 and equation 18) while the whole stiffness of the girder is raised by such fixing; the formulæ for flexible struts are therefore not given.

In addition to the stresses arising from the force calculated from equations 1, 2 and 3, bending stresses are also set up in the flanges due to the pull of the web sheet on these parts.

The bending moment is a maximum at the points of attachment of the web struts and is

$$M_F=Sd^2/12h\ .\ \tan\alpha \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

If the resistance of the flanges to bending is small then the pull of the central parts of the web becomes ineffective (Fig. 3), it is then necessary to evaluate the expression

$$wd=1.25\ d\ \sin\sqrt[4]{[t/(I_t+I_c)\ h]} \quad . \quad . \quad . \quad . \quad (12)$$

where I_t and I_c are the moments of inertia of the tension and compression flanges about their own centroidal axes, and from Fig. 5 to obtain a value for the constant C_1. Then a new bending moment

$$M^1{}_F=C_1M_F \text{ can be derived.} \quad . \quad . \quad . \quad . \quad (13)$$

In the case of flexible flanges, the equation (1) gives only the average stress in the web sheet, the max. stress is

$$f_{max}=f_{average}\times 1/C_2 \quad . \quad . \quad . \quad . \quad . \quad (14)$$

the value of C_2 also being obtained from Fig. 5.

In most wing constructions the spars taper, thus part of the shear is taken on the flanges direct, the amount taken by the web being the difference (Sw) of the total shear and the vertical components of the flange forces (Fig. 4). Wagner gives this case special treatment as indicated in Ref. 10, page 1, *et seq.*

The main fact established is that the web stress varies over the depth of the girder. At the same time the stress is constant along the length of any wave, thus the stress at the point A on section AB (Fig. 4) is the same as at A^1 and the stress at point B is the same as at B^1.

The stress at the point A is given as (Ref. 10, page 5)

$$f_A = f_m (h_x^2/h_1^2) = f_{m1}/(1 - \cot \alpha \tan \delta)^2 \quad . \quad . \quad . \quad (15)$$

$$f_B = f_m (h_x^2/h_2^2) = f_{m1}/(1 + \cot \alpha \tan \delta)^2 \quad . \quad . \quad . \quad (16)$$

$$\text{where } f_m = (Sw/h\varpi t)\, 1/\sin \alpha \cos \alpha \quad . \quad . \quad . \quad (17)$$

In the above, the boom angles δ and γ are assumed equal.

The strength of the verticals secured to the skin is derived by means of Fig. 6. The elastic support given to the verticals, results in what is, in effect, a reduction of the slenderness ratios or a virtual reduction of lengths of those members and the virtual length l^1 is given by

$$l^1 = C_3 l \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (18)$$

C_3 being obtained from Fig. 6. Using this effective length and the loads V or V_n the strength of the member as a strut can be obtained from the " strut curve," allowance being made for the " effective width " of attached material.

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Discussion

The Chairman: The author had given a very able exposition of the work that has been carried out by him at Bristol and it was considered by the Air Ministry to be very important work as would be recognised by the indication given by the author that the Air Ministry had helped to finance it. It was sometimes simple to get money, continued the Chairman, but it was not always easy to get men able to carry out research work of the right character. In Mr. Pollard, however, working with Captain Barnwell, they had found a combination which amply satisfied the Air Ministry, and he was glad of the opportunity of saying so. As regards the purpose of this work, he was disposed to agree with the rather neat summary given by the author in his paper, where he said that provided this kind of information was obtained then the chance of success in design will be much greater than would be the case if the new design were based on a few experiments unconnected by logical deduction. The author was trying to make logical deductions which would connect one design with another, and in this particular subject that was very difficult because there were so many candidates for the honour of bearing the stress and in this, as in other matters, where there was divided responsibility troubles arose. From some of the pictures that had been shown it was difficult sometimes at first sight to see, when any failure took place, to what particular aspect of the construction that failure was really due. The work that had been done bore testimony to the ability of Mr. Pollard, even though he had frankly to confess that there were enough variables in the construction to keep the problem new for some years to come! No doubt that represented the heartfelt view of the author. One of the features of this method of construction was the great stiffness which it offered. Research work recently in regard to wing torsion, flutter of every kind and tail buffeting had indicated how easy it would be to build an aeroplane which would be amply strong enough for ordinary stresses, whilst failing in stiffness; so that the kind of construction which would give the strength that is needed and the stiffness, an increasing need with increasing speeds, was very necessary.

Mr. S. C. Redshaw (Associate Fellow): Referring to the statement in the paper that, in a box type of construction, the spar webs were assumed to take shear loads only while the covering would be subjected to both shear and direct stresses, he suggested that this was not altogether justified. The spar webs would be called upon to take direct stresses, caused by bending, in addition to the shear stresses. As a result the web would tend to wrinkle close to the compression flange and in consequence the shear tension field formation would be affected and the strength of the spar lowered accordingly. If the strength of the web was calculated from shear stresses only a flattering estimate of its strength would probably be obtained.

Perhaps the author could say if the predicted critical shear stresses for webs of this type was higher or lower than those obtained by mechanical tests.

With regard to the author's remarks concerning atomic-hydrogen welding, he believed the average welder was not able to weld sheet thinner than 18 gauge by this method. The author had mentioned .02 inch for the thickness of the covering, did this render atomic-hydrogen welding too expensive or impossible to be generally used?

Mr. W. D. Douglas (Associate Fellow, Royal Aircraft Establishment): Stressed-skin structures become extremely complicated from the structural point of view as soon as the skin is fitted with a stiffening system. An enormous number of variables creep in and any attempt to treat them one at a time experimentally would provide a programme which would stretch far into the future. It was very frequently convenient to consider a structure like a stiffened stressed-skin structure as divided up into components, but whilst it was convenient it was sometimes dangerous to draw conclusions founded on the assumption that the parts could be regarded as separate structural units. One might be led into

error in adopting that course and therefore it was necessary to examine one's conclusions very carefully. In general, a stiffened skin might be regarded as a tubular form of construction fitted with stiffening members some of which ran longitudinally—and might be called stringers—and others ran transversely—and might be called rings or hoops. The author had referred to the investigations at present being carried out by the Air Ministry in which considerable attention was being paid to variation of the form and spacing of the stringers, the hoops, for convenience, were being retained at a constant distance apart. But the hoops and stringers were really parts of the whole and could not be considered as acting separately. Therefore, if that investigation were to be completed it must of necessity be extended to include variations of spacing of the hoops and stringers. He believed it was generally considered at the present time that the form and spacing of the rings is not as important as the form and spacing of the stringers and for that reason the stringers were obtaining the first innings. The application of theory to a problem like this was always of great interest and although in the early stages theoretical conclusions might occasionally be regarded merely as of academic interest, eventually, by introducing refinements in the mathematical methods and in the underlying assumptions, theory was almost bound to give a lead to the experimentalist. But it was again necessary to sound a note of caution. Frequently the results which were obtained from the theory in the early stages might not be quite sound in their application to practice because of the necessity for simplifying the assumptions which had been made and in that connection he drew attention to a quotation by the author from Mr. Redshaw, which stated that the theoretical critical stress in a curved skin construction in compression was practically independent of the length of the specimen. The author accepted that straightaway as indicating that small specimens could be used, but that conclusion could not be pressed to the limit. It was known from practical considerations that with short specimens there were certain end effects due to the impossibility of introducing shear and end load into the specimen with the same distribution as existed in the actual elements of the complete fuselage. Therefore, whether or not we could justifiably use short specimens could not be determined merely by calculations but must be checked by experiment.

The author quotes the formula $\{\sqrt{(\text{Shear load in lb.})}\}/(\text{Depth of girder in inches}) = \text{Const.}$ in connection with the design of spar webs. Since this formula is dimensional, the values of the constant which are mentioned refer, presumably, to some particular material. If so, it would be of interest to know which material was intended.

Further on, the author referred to the effect of end load on the shear buckles in the webs of spars and suggested that probably these would be affected by the presence of end load. In this connection it was interesting to look at Fig. 7. In that illustration there were some well marked shear buckles in the webs. In that particular specimen a pull was being applied towards the right hand side of the illustration so that the (vertical) boom on the left would be in compression and that on the right in tension. The illustration did not show much difference in the appearance of the buckles near the two booms. Presumably, if the end load had any great effect on the form of the buckles one would expect the buckles to be running in a direction more or less perpendicular to the boom on the compression side and in a direction tangential to the boom on the tension side. That illustration, therefore, suggested that probably the effect on the shear buckles was not of any great practical significance so far as that type of spar was concerned.

Mention had also been made in the paper of some experiments carried out by the author on riveted and welded spars under fluctuating stress. It would be interesting to know whether those tests were made on a basis of stress or strain. He believed he was correct in saying that they were on a basis of strain

because in the illustration the two spars were being tested at the same time and therefore presumably both were being given the same displacement. If that were so, presumably the tests were on the basis of strain. In that event, would the stress be of about the same order in each spar or were the spars, made by two different processes, of about the same bending stiffness?

A rather strong point had been made of the fact that any vibration test of complete spars, to be of use, should include representative fittings, holes and accidental irregularities. The spars shown in the illustration appeared to have loading boxes at the points at which the vibrating mechanism was attached. Could the author say whether the failure he got in these spars was influenced by, or was directly due to, the presence of these fittings and, if so, was it quite fair to judge the relative merit of the two processes on the results of such a test unless the loading boxes had been specifically designed to suit these processes?

The CHAIRMAN: He was pleased to see Miss Chitty present. She had just been elected a Fellow of the Society and was the first woman to be so admitted. As Miss Chitty had been associated with some of this work, he asked if she would take part in the discussion.

Miss L. CHITTY (Fellow): She was unable to contribute to the discussion as it was ten years since she was associated with Mr. Pollard in work on metal construction. However, listening to the lecture, she had been impressed with the great strides that had been made since that time, when they were feeling their way, more or less, as regards transferring to metal from wood. The field of research was enormous and it was important that the practical and theoretical considerations of constructional problems should go hand in hand. Dealing purely with the theoretical there was always the fear that one was being led away from the practical in directions which were convenient for the mathematics. In carrying out theoretical work, therefore, it was essential always to keep in mind the relationship of theory and practice and from that point of view the paper was of special value to her.

Mr. M. LANGLEY (Associate Member): The paper was specially interesting because it indicated that at long last " metal-clad " construction seemed to be coming into its own. The Bristol Company and Messrs. Short Bros. were among the first people in this country to be interested in the metal-clad fuselage. It was satisfactory to find that early work vindicated after something like 15 years. The paper was also particularly valuable in that it translated into engineers' language work which had existed for many years in mathematicians' language and as such it would be appreciated by all the technical and engineering members of the Society. One of the principal reasons why the metal-clad system had not developed was lack of knowledge, and the author had now in a large measure made that good. Another reason was the prejudice that existed against it, and he used the word " prejudice " in its truest sense, viz., pre-judging the issue on insufficient data.

Another prejudice against metal-clad was the feeling that such structures were more expensive than the braced structure with fabric covering. Perhaps it was too much to expect members of the Society having experience of both types of structure to come forward with actual figures of the relative costs. If such information was available, he did not think it would be fair just to compare the two types of structure on initial cost. One very important aspect was the subsequent maintenance cost. If that were taken into account he believed the result would be to the advantage of the metal-clad.

Incidentally, Mr. Langley said he used the term " metal-clad " in the same sense that the author used the expression " stressed skin," because he found the latter rather difficult to say! He also used it deliberately, because although he had made a fairly wide search he had found it very difficult to find examples of pure " monocoque " construction, except in very small machines such as

single-seater fighters and light aeroplanes. The monocoque hardly existed at all in the large machine, due to difficulties with the concentrated loads at the wing root. This was emphasised by a consideration of the Junkers machines. In that case, with a multi-spar there was presumably less concentration of load at the joints than with the normal wing structure. Yet the reactions were transmitted not into the metal skin but into the braced section of the Junkers fuselage. They gradually died out towards the tail as the loads became less, and the stresses could be more easily taken by the metal skin. But this could not be called "monocoque." Similar constructions were used or had been used by Spartan, Handley Page, Loire, Breda, and a number of other firms for building commercial and large size machines. Another form of metal-clad construction was that in which the skin was used principally as panel bracing against shear, the basic structure consisting of longitudinal and transverse members. Such an arrangement was used by Fiat, Dornier, Dewoitine and others. In both cases, presumably, one may take a certain width of metal skin as acting in conjunction with the frame members, both in tension and compression. In calculating this width of skin the author quoted a formula which was, he believed, Von Kàrmàn's. But Mr. Cox in his R. & M. 1553, to which the author referred, appeared to support Pietzker's theory that one could take fifty times the thickness of the skin as working with the basic members. Mr. Pollard, however, did not mention Pietzker. Were they to take it that he had compared Pietzker and Von Kàrmàn and had come to the conclusion that Pietzker's rule was much too crude for aircraft? Personally, said Mr. Langley, he had not had time to compare them, but if they had been compared he would be very interested to know what was the relation of the one to the other. Finally, Mr. Langley thanked Mr. Pollard for pointing out the advantages of metal-clad structures, and added that if there was no secondary structure in the way of fairings, etc., then they were making every ounce of weight do some work and earn its living. He felt that if one concentrated the loads into as few structural members as possible and had a considerable amount of secondary structure standing idle, it would almost inevitably result in greater weight. He hoped, indeed, he was sure, that this paper would do a lot towards killing the prejudice that had existed against metal-clad construction.

Mr. H. A. METTAM (Fellow): It was very interesting and of the highest importance to other firms in the industry to have papers of this kind in which the results of practical tests were correlated with the mathematical formulæ. It still appeared from the paper that the design of stressed skin structures was a matter for the engineer, and in that connection he said he wished to define an engineer as the man who was capable of making reasonable assumptions based upon insufficient data! It was certainly very desirable to have mathematical formulæ developed simultaneously with practical testing.

The author had restricted the appearance of buckles to one-third of the fully factored load, but it would be useful to know if that was consistent with the three-quarters yield requirements insisted upon for military aircraft and if it could be assumed that buckles appearing at one-third of the fully factored load would be fairly elastic.

The next point was, in using Von Kàrmàn's formula, did the author consider the values given for constant C in his Reference 4 were correct or had the author any different experience on the point? (Since this paper had been prepared Technical Note No. 479 had been issued in America and that appeared to give a rather different law for the variation of permissible stresses with thickness over radius than the one which the author quoted in his Reference 1.) He did not know whether the author had had time to make a comparison of that kind. If so, it would be of great interest, because there were three alternative curves, A, B and C in T.N. 479, and he would like to know which of these the author would use.

It appears that the desirability of stressed skin construction must depend to a marked extent on the size of the aircraft under consideration. Figures given by Dr. Dornier, in the Journal for December, 1928, show the weight added by metal covering of wings for different aircraft. For the Dornier Libelle of 1,120lbs. all-up weight, the metal covering was 41.7 per cent. of the total wing weight, while for the Dornier Super Wal of 10,300lbs. all-up weight, the metal covering was only 23.3 per cent. of the total wing weight. It would be interesting to know at what stage in the size of aircraft the author considered that stressed skin construction would be worth while from the point of view of weight.

Mr. D. L. Hollis Williams (Associate Fellow): Remarking on the manner in which stressed skin construction has lagged behind in this country in comparison with continental designs, he believed the reason was that British designers are so conventional. Fabric was about the only material which had never given any trouble and braced structures had fitted in with their national policy, or rather what had been their national policy, of steel construction. Thus they had developed braced biplanes up to a high pitch of efficiency. It was only now, when they had found they could not get the last ounce out of our highly efficient biplanes that they had been forced to consider the design of cantilever aircraft and the question of stressed skin construction more than had been the case in the past. Another point that had not been mentioned was that with fabric cover in the case of a thin wing was at high speeds not subjected to high local pressures, but the thicker wing that had not the same capacity, due to its heavy camber, of being relieved. There were very big opposing forces on the top and bottom surfaces of highly cambered aerofoils, and fabric, if used, became corrugated and would eventually tear, and it was because of this that they would, eventually, have to have recourse, on the high speed machine, to the metal cover. One big objection to the metal cover, however, which must be got over before it could be adopted on a service basis, and that concerned the lack of facilities for inspection. That did not, perhaps, apply to the fuselage because it was possible to crawl down the fuselage for the purposes of inspection, but in the case of the wing the tendency was to build a box which was riveted up and became more or less like a salmon tin and the only way to get into it was by means of a tin-opener, That was a very big objection which must be overcome, by careful design, before monocoque construction was likely to become a serviceable proposition.

Reply to Discussion

Mr. Pollard, in reply to the discussion, first thanked the Chairman for his remarks.

In answer to Mr. Redshaw, he said that the effect of longitudinal stress at the edges of sheet webs, adjacent to compression flanges, had not received detailed study. Puckering of this part of the web under end load might be important. He had little data on the subject, further experiments were needed.

When Mr. Redshaw spoke of 18 G. as the minimum thickness of material that could be welded by the atomic-hydrogen process, he must have had in mind a light alloy type of material. He had seen a lot of steel strip, only 0.005in. thick, welded successfully by that means. In regard to the welding of aluminium alloys by atomic-hydrogen, the fact is that the amount of work done in this connection has been limited. Aluminium and aluminium silicon alloys down to $\frac{1}{16}$in. thick, have been welded. His remarks on atomic-hydrogen welding referred only to steel (girder type) constructions. It was far too early yet to consider it as a means of final assembly for light alloy sheet metal constructions.

Mr. Douglas suggested that the spacing of the rings was not as important as the spacing of the stringers—we must not allow the importance of stringers to force hoop spacing out of consideration. Precedence had to be given to one or the other and the problem of stringer spacing had been tackled first.

As Mr. Douglas said, he accepted straight away Mr. Redshaw's deduction that the theoretical critical stress was practically independent of the length of the specimen, but, as stated in the paper, practical considerations must be kept to the fore and using any theoretical deductions, it is necessary to ascertain how such deductions fit in with practice and modify accordingly. " End effects " on a specimen is a practical consideration and, as Mr. Douglas states, the extent of the region subjected to such effects can only be determined experimentally, this point has been realised for many years.

As to the ratio $\{\sqrt{(\text{Shear load in lb.})}\}/(\text{Depth of girder in inches})$, this refers specifically to webs made from aluminium alloy.

The deduction made by Mr. Douglas in reference to Fig. 7 was largely the answer to Mr. Redshaw's comments and question on the effect on the web in shear of superimposed longitudinal compressive stresses. It is reasonable to suppose that puckering in the web adjacent to the compression flange of a spar will affect the strength of a spar in some degree; at the moment there is little experimental data on the point.

In regard to the vibration tests on the spars, the spars were tested in pairs and each was subjected to the same amplitude, the same static loads applied separately and the deflections of the spars were the same. The spars were identical in regard to material and dimensions, thus the stress and the strains were the same in the two cases.

The failures that occurred in the early tests were due to discontinuity at the loading boxes, for later tests the loading boxes were re-designed to give as gradual a change in stress as possible, and in some of these cases fractures were obtained for spars made by both processes, at places well away from the loading boxes. It is thus quite fair to judge the relative merits of the processes by the results of these tests.

If the loading boxes were not designed to suit a particular assembly the results of the test would be influenced by the design of the boxes, consequently, it would not be fair to judge that process or the material on the results of such tests. Tests of the kind illustrated quickly show whether a loading box or other part is adversely affecting the strength of such a spar in fatigue and strengthen the argument for the inclusion of such parts on dynamic test spars. Fundamental information on fatigue of materials should, of course, be obtained by other means, but tests of the form shown are necessary for the determination of the *real* fatigue strength of aircraft structures.

In regard to Mr. Langley's very useful contribution to the discussion, he would say, in the first instance, that the question of the provision of lengths of braced girder construction into the design of the fuselage in order to accommodate concentrated loads was not, in his opinion, the final answer to the problem. It was an easy way out. The design and manufacture of stiff bulkheads and the attachment of these to the skin without the introduction of local weaknesses was the more difficult problem and involved full-scale testing. Lack of knowledge has been the main stumbling block. He expects in the future to see fuselages metal-clad from end to end, ample provision for concentrated loads being provided in a simple, efficient and safe way.

Mr. Langley had also mentioned costs; in this connection one can only say that there appears to be nothing inherently expensive in stressed-skin constructions, not even riveting. The difficulties that were encountered with the first structural units of metal aircraft, that is to say, steel strip spars, ribs, longerons,

etc., are still remembered; the troubles were all surmounted in time, but in the case of these shell-type constructions, no special difficulties present themselves. Costs can be kept down through the adoption of " developable surfaces " which makes possible the use of sheets of the largest possible area. Thus the number of " edges " is reduced to a minimum. This is a very important matter, since, while close pitch riveting depending on the thickness of the sheeting is necessary at edges, yet much wider pitching may be used away from the edges. Such simple considerations as these, together with intelligent use of jigs and training of personnel will undoubtedly place the costs of these constructions in a very favourable light compared with other types of construction. Mr. Langley mentions maintenance costs, experience is still required in this connection, but it will be altogether surprising if this is not reduced to a very low level. As to a comparison between Pietzker's rule and Von Kàrmàn's formula, all he had to say was that the latter agreed very well with experimental results.

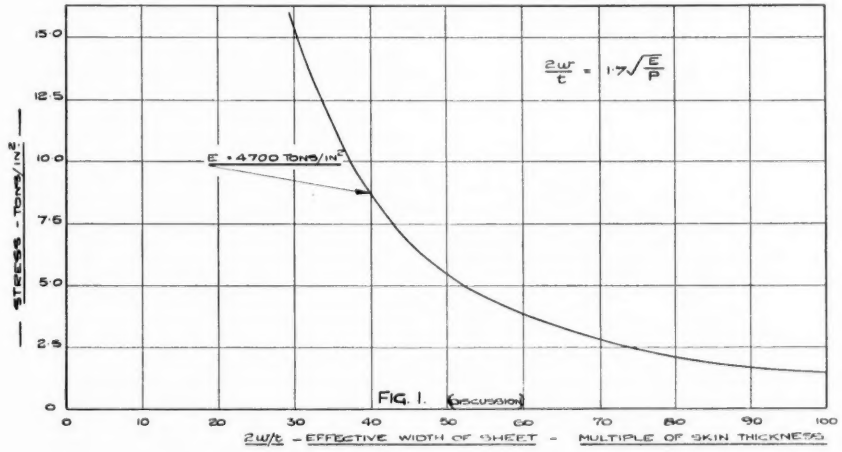


FIG. 1. (DISCUSSION)

[The formula is plotted in Fig. 1 appended; there is apparently no reason why it should be assumed that the effective width of sheet was constant at 50 times skin thickness.]

Mr. Mettam's definition of an engineer is certainly what one's working life consists of. In answer to the query on the permanence of buckles, it had been his consistent experience that buckles appearing at about one-third the fully factored load never had been permanent at three-quarters the fully factored load. That, of course, could not be taken as a law, but it had been true in his experience. If external buckles were allowed to appear at one-quarter the fully factored load (which could scarcely be permitted on an aircraft whose load factor was four) permanence of buckle would not in general be induced at three-quarters fully factored load, although permanence, *i.e.*, yielding of the material, in this case, might be close at hand.

In regard to the constants in Von Kàrmàn's formula. In comparing calculated with measured buckling stresses, the values of C used in estimating the effective width of the sheet were those given in Reference 4 and the estimated and measured crippling stresses were in fair agreement. Only a few tests had however been made, the matter was receiving further experimental verification at the present time. He regretted that he had not had the opportunity of comparing data given in N.A.C.A. Tech. Note 479 with that in Reference 1, but

he noticed that the title of Tech. Note 479 was " Stability of Thin-walled Tubes Under Torsion," whereas Reference 1 had to do with metal monocoques in bend, so that comparison of permissible stresses with the ratio, thickness over radius, might be a matter of some difficulty for the dissimilar cases.

A full answer to the last part of Mr. Mettam's question would occupy more time than is available, a brief answer only is possible now. There is no object in using metal covering if it does not contribute to the strength or stiffness or both of some part of an aircraft. For example, it was not economic to have rigid covering between, say, the rear spar of a wing and the trailing edge unless use could be found for such covering to give support to the aileron.

Experience had already shown that, even in the case of a small single-seater, a monocoque fuselage could be built lighter and stiffer than could a faired girder fuselage for the same aircraft.

As Mr. Mettam pointed out in his comparison between the Dornier Libelle and the Super Wal, the skin weight becomes a smaller percentage of the whole as the size is increased.

It must be remembered that as regards wings, the use of metal covering can be considered for monoplane surfaces only, or for really large biplanes, larger than any that have been built in this country to date. This matter is dealt with briefly in the paper. So far as Mr. Mettam's question relates to biplanes, therefore, one is unable to say at this stage when metal covering of the wings would pay; but for monoplanes, having regard to the high stress development rendered possible by such covering, then stressed-skin construction is a feasible proposition for single-seaters and becomes more economic for larger machines, having regard to the less percentage use of material of minimum practicable thickness.

Flutter may easily prove to be the deciding factor in wing design, consequently a word of warning is necessary as to wings of minimum possible weight and criteria of flexural stiffness. Torsional stiffness criteria appear to be well within the prescribed limits in cases where rigid covering is used in the manner described in the paper, but the bending limits may easily be exceeded. It is therefore necessary to pay due regard, for example, to the chord-depth ratio of wings in relation to flexural stiffness and to ascertain the influence of this on the performance of the aircraft if an unusually large ratio appears to be necessary. Where this has reached the limit, or if it is considered that the weight of the wing structure should not be raised either by increasing the number of spars or the mass of metal in the existing spar flanges, then recourse to a form of wing construction involving external bracing becomes imperative.

He entirely agreed with Mr. Hollis Williams that our conventionality was a very good reason for the delay in constructing metal-clad aircraft in this country. It is becoming pretty clear that there is not much left to go for in biplane construction for small and medium-sized machines. The point of possible dangerous localised loading of the fabric of high speed aircraft had certainly been missed and he thanked Mr. Williams for drawing attention to it.

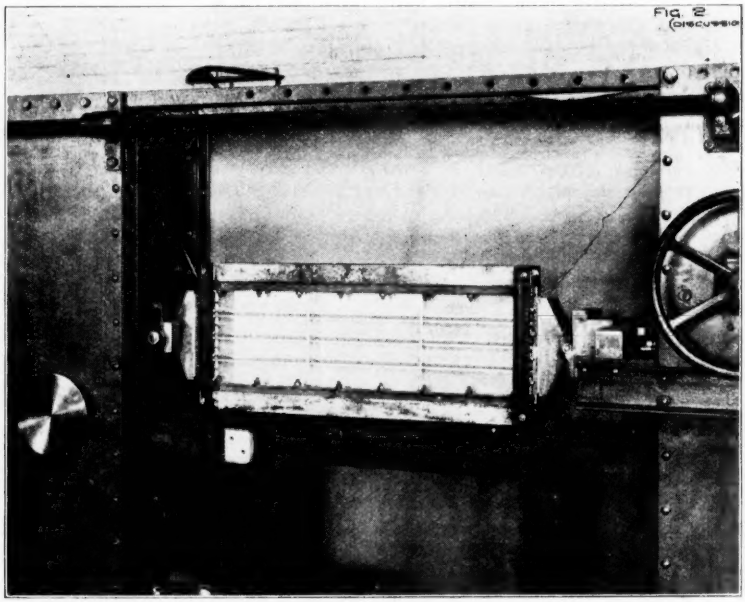
The necessity of providing holes to allow of internal inspection was one of the major problems—fairly large apertures are indispensable. Every part of the structure, internal as well as external, should be easily accessible; by careful design the number of holes necessary can be reduced to a minimum. Such holes as are provided must not, of course, weaken the structure, and as indicated in Appendix III of the paper, the necessary experiments on the subject of suitable reinforcement of holes could be investigated by comparatively simple means; doubtless, constructors would do their own experiments in this connection. He did not think this matter was likely to impede progress with this type of con-

struction. The provision in wings of really large apertures for retractable undercarriages, etc., was a special problem and a definite primary structure must be incorporated in such cases. But in the case of cockpit openings and the like in fuselages, no special difficulties had as yet been encountered. There still appeared to be plenty of skin and internal framework left to take the loads without the addition of much extra reinforcement in these cases.

COMMUNICATED

I had hoped that with the publication of the paper in the Journal to give some information on the effect of longitudinal stress at the edges of sheet webs on the strength of such beams, together with any useful data that might be derived on wrinkling, due to combined shear and end load, but much more time is required. Mr. Douglas, in his contribution to the discussion, had made some observations on this point in regard to Fig. 7, and he had nothing further to add now.

Further to the question of relative positions of hoops and stringers. Investigations on " hoop " spacing had started in Bristol, as shown in Fig. 2



Investigation on " hoop " spacing.

(discussion). The strength of a series of reinforced plates (flat in the first instance) was under investigation, each plate had three stringers secured to it, the variant being the spacing of members placed transversely to the line of thrust.

Each plate was given simple support along the long edges while the thrust was exerted through knife edges and was applied in a plane containing the C.G. of the combination of plate and stiffener and parallel to the sheet.

The specimen shown in the testing machine had two transverse members. This series of tests was throwing some light on the obscure matter of transverse stiffener spacing.

The next step was to repeat the experiments on curved plates similarly reinforced. If a basis of comparison could be formulated between these experiments and tests on one or two actual bodies, then the problem of hoop spacing would be well on the way towards solution. Not sufficient data has as yet been collected to establish the relative importance of stringer and hoop spacing; from what has been done to date, it is reasonably clear that in the ultimate solution of this problem and cost reduction was part of the problem, the spacing of hoops will be found to be an effective factor.

REVIEWS

Handbook of Aeronautics

Vols. I and II. Published by Sir Isaac Pitman and Sons, Ltd. Price: Vol. 1, 25/-; Vol. II, 15/-.

This work is the second edition of the " Handbook of Aeronautics," and it is now published in two volumes. The first deals with aeroplane matters and certain miscellaneous subjects; the second is concerned solely with engines and several cognate matters.

The first volume starts with aerodynamics, which subject is in the able hands of Mr. Relf. The matter is on similar lines to that given in the first edition, and it is as complete a review of the main principles as the aircraft designer would normally require. A better selection might be made of the examples of aerofoil data. R.A.F.14 is obsolete nowadays and could be replaced by Clark Y; and one or two of the American M sections might be added, as these are popular with the designers of monoplanes. Again, in the vector diagrams giving rolling and yawing moments, the first diagram is concerned with an Avro-shape monoplane. This phrase does not convey any particular meaning to-day, but it is probable that data of this type is not available for modern aircraft. These are, however, small points, and it only remains to say that the matter is well chosen and well set out and illustrated.

Captain Liptrot again treats the subject of performance, and has added to the information previously given, though keeping on the same general lines. His contribution is one of the most useful in the book, and is a mine of information on its subject. It is to be hoped that it will be possible to add a few modern body-shapes to the list of typical bodies given in future editions; some of those illustrated date from very early days. But it is probable that here, also, lack of data on modern bodies is the cause.

Construction is in this edition dealt with by Mr. Langley, who has written a very useful section on this matter in which he gives much useful information on metal spars of various types, and also on available materials, methods of jointing, etc. Wooden construction is still largely used for small aircraft, and a reference to the usual types of wooden spars, ribs, struts, etc., should be included.

Colonel Outram has contributed the materials section, and his notes on this subject are most valuable. Protection against corrosion is well dealt with—as it should be in these days of metal construction. Testing methods, heat treatment, the colour index, A.M. specifications, etc., all find a place, and all the usual information a designer may want on this matter is given.

Captain Entwistle deals with meteorology, and his contribution is exactly what is wanted in a book of this type; while Mr. Stewart has written a useful article on aircraft instruments. Major Kemp's contribution on air survey and photography contain a quantity of useful data, and the first volume closes with an article on design data and formula by Captain Pritchard.

This subject does not possess much scope for novel treatment, but there is a reference to Mr. Howard's method of using polar co-ordinates in place of cartesian, the advantages being pointed out. Stress calculations, generally, are explained in detail, and such matters as H.P. slots and other devices are dealt with in their effects on spar loads. The section is excellent and contains all that is necessary for normal stress work.

Captain Latimer Needham contributes an article on the design and construction of gliders and sailplanes which should be of great use to the designers of these machines.

Vol. II is written entirely by Mr. A. Swan, and this section has been enlarged considerably. Much matter has been added on stress matters, superchargers, radiators, etc., while the subject of vibration receives adequate treatment. This part of the work is almost a textbook in its treatment of its subject, and should be of great value not only to designers of aeronautical engines but also to those engaged on the design of marine and automobile types. It is well illustrated and clearly written.

This new edition can only be described as being an immense improvement on the old. The paper and type are much better, it is easier to read, the diagrams are clearer, there is an adequate index, and good biographies are added at the end of every section. The result is that the old edition is now completely out of date. It is an invaluable reference book for aircraft or engine design.

Metal Aircraft Construction

By M. Langley. Sir Isaac Pitman and Sons, Ltd. Price 15/-.

This is the second edition of this work, and it has been revised in certain sections in order to bring it up to date. New matter has been added, especially in connection with Continental practice, but it seems that some American firms are still inclined to secrecy as regards their methods of construction, so that, with certain exceptions, this part of the book is not very complete.

As it stands, it is a most valuable treatise on metal construction, for it brings together under one cover the diverse solutions that have been found by various firms for the various structural difficulties. These different solutions, which often refer to identical problems, can be compared, not only as regards structural rectitude, but also in regard to the conflicting claims of weight and cost.

It is clear that the structural design of metal aircraft is at present in a state of flux. The number of different solutions to problems being the same as the number of firms designing the part in question. These different solutions cannot all be the best, but it must be left to time and experience to weed out the inferior. In the future, when design has settled down, it is likely to be more stable, for the reason that the fittest will have survived from a large number of the fit.

The book is excellent, both in matter and illustrations, and can be thoroughly recommended.

British Aeroplanes Illustrated

C. A. Simms. Published by A. G. C. Black, Ltd. Price 3/6.

This book consists of photographs of standard British aeroplanes with a short description of each. There are included 21 military types, three record-breaking machines, and 21 civil aircraft. The photographs are well chosen, and are reproduced by some form of photogravure process in sepia which gives excellent results. The letterpress accompanying each illustration is confined to a short description of the purpose for which the machine is intended, with a few notes on dimensions, horse-power, etc. These are not always correct, for instance, the span of the Vickers Victoria is given as 29 yards. Why yards are used in this instance alone is not clear, but, in any case, the figure is wrong.

As a help for recognising types of aircraft in flight, the book should be useful, and it also should have an appeal to those members of the general public who like to have a general acquaintance with aeronautical progress. It is very good value for the price asked.

The 577th Lecture read before the Society since its foundation, January 12th 1866.

THE ROYAL AERONAUTICAL SOCIETY

The Sixth Meeting of the second half of the 1933-34 Session of the Royal Aeronautical Society was held in the lecture theatre of the Royal Society of Arts, 18, John Street, Adelphi, London, W.C.2, on Thursday, April 19th, 1934, when Air-Commodore P. F. M. Fellowes, D.S.O., lectured on "The Houston-Everest Flight." In the chair: Colonel Lord Sempill, Past-President of the Society.

The CHAIRMAN: They extended a very warm welcome to Air-Commodore Fellowes, who had recently returned from a lecture tour in the United States of America, where he had delivered about fifty lectures. The Chairman recalled that a year or more ago, when those concerned with the arrangements for the Houston-Everest Flight were considering the selection of a leader for the expedition, naturally many names were considered, but without much delay it was unanimously decided to invite Air-Commodore Fellowes to accept the leadership. That was a very wise course, in view of his long experience, and as shown by the great success of the expedition.

THE HOUSTON-EVEREST FLIGHT

BY

AIR COMMODORE P. F. M. FELLOWES, D.S.O.

In this paper I propose not only to comment on the lessons learned in the flight over Everest and Kangchenjunga, but also to indicate approximately what is involved in the initiation and organisation of such an expedition. It can only be on the rarest of occasions that a scheme emerges full-fledged from the nests of the mind and this expedition was no exception.

At first the adventure of flying over the highest peak in the world was the lure and the aspect which loomed largest in the minds of those of all nations who contemplated such a flight. Gradually as the scheme and the possibilities of this expedition unfolded itself, the broader and more scientific ends became apparent.

The photographic and survey facilities offered by the single-seater were first discussed and discarded, and when Captain Uwins took a Vickers Vespa, engined by the Bristol Pegasus, to 44,000 feet he confirmed the opinion that a fully-equipped two-seater could be used for the attempt, and that the Pegasus was the most suitable engine for the task. This opened up a new situation full of interesting and scientific possibilities, and enabled a much greater field of effort to be included in the purposes of this expedition.

Primed thus, Colonel Blacker, the originator of the idea, and Colonel Etherton, ably supported by Squadron Leader Lord Clydesdale, obtained a sympathetic backing from the Royal Geographical Society, the India Office and the Air Ministry, and without their countenance nothing could have been achieved. They then embarked on the difficult task of forming a really influential committee. Thus supported they initiated negotiations through the India Office, backed by the Air Ministry, to obtain permission through the Viceroy, who was most sympathetic, to fly over Nepal. It might be thought, with all this weight of authority, that this permission would have been easy to obtain, but there were

not only the feelings of the gods of Everest to take into account, but also Great Britain's old-fashioned and, I am sure you will agree, very undeserved reputation.

I refer to the unjust suspicions which in the past have constantly been hurled at our innocent heads of taking any excuse to remain in any country in which circumstances involved us.

The Nepalese authorities feared a forced landing, and it was only when they were convinced that such a contingency was in the highest degree unlikely that they consented to one flight directly in and out from Everest, with the possibility of a second flight if the first one was completely successful.

From the point of view of the feeling of the gods, do not let us blame the Nepalese beliefs too sharply. We ourselves do not live in the presence of these stupendous peaks, and even in a scientific assembly such as I am speaking to, I will wager that there are some who will not willingly walk under a ladder or light three cigarettes from one match. The investigations and appraisement of the vagaries of the mind in different parts of the world and its effect on plans is as truly scientific as any other investigation. I therefore make no apology for its introduction.

The preliminary detailed plan, the political necessities, and the interest of an influential committee having been established, the perpetual stumbling block to all action in this world, insufficient funds, had still to be surmounted. This was achieved by a deputation of one, Lord Clydesdale, who secured the very generous contribution of £15,000 from Lady Houston, and let us here pay tribute to the outstanding imagination and patriotism behind this gift.

Meanwhile, Blacker, Etherton and Clydesdale had all three been amassing information on all aspects of the expedition. It then became necessary to secure the services of somebody with sufficiently recent experience in the formation and operation of flying units to take charge, and it was at this stage that I entered the field.

The first step taken after the procurement of the funds, which actually became available on November 16th, was to ascertain the final date from a meteorological and consequently insurance aspect on which the flight could be carried out. This was decided by the onset of the first effects of the monsoon along the Himalayas and was given as April 15th, with a possible extension to May 1st. It was now November 16th, so there were just five months in which to purchase and equip the aircraft and engines, adapt and devise the necessary apparatus and instruments, test the aircraft, etc., select, test and train the personnel, decide upon the fuel and oil, plan out the route and fuel arrangements, ship the aircraft overseas, erect and test them on arrival in India, prepare the bases, erect the hangars, arrange for the meteorological data required, perfect the scheme of operation in consultation with the military and air force survey and photographic authorities, carry out the preliminary weather reconnaissance and tests in the actual area of the flight, and finally make the major flights. The speed with which preparations had to be pushed forward meant that a number of speculative decisions had to be made, but fortunately they all came off.

When the time limits were first given to Messrs. Westland and Bristol, they frankly said they thought we had set ourselves an impossible task. But thanks to their and Messrs. Williamson's unexceptional work, and the preliminary preparations made by the first Triumvirate and the unlimited technical advice and assistance given by the Air Ministry, and in particular, A.M.S.R. and the R.A.E., Farnborough, the second aircraft was ready for shipment one day and a half before the ss. Dalgoma, the last possible ship, left for Karachi. As these ships leave at intervals of a month, any further delays would have meant the postponement of the expedition until the autumn. Three things looked as if they would hold us up at the last moment. The flexible driving shaft of one of the petrol pumps snapped. A speedy analysis of such happenings showed that these failures had invariably happened in the first few hours of their use. A very

stringent ten-hour running test of this piece of machinery was carried out, and a replacement and two spares were provided. The second interesting difficulty which cropped up was that we had omitted to inquire as to the exact size of the hold in the ss. Dalgoma. This produced a crisis, as the planes with their engines and a majority of their equipment installed, had only been packed to be tilted to 30 degrees, and they had to be tilted to 60 degrees to get them in and out of the hold.

By very careful handling in England and India this difficulty was surmounted, but Messrs. Westland regarded this so seriously that they asked me to promise personally to be present at both the loading and unloading.

The third difficulty was caused by the cameras. Both the film cameras, cinema and vertical, became very temperamental in the extreme cold, but this difficulty, too, was overcome as a result of tests in a refrigerating chamber.

Both aircraft were tested to 35,000 feet in a temperature of minus 79 degrees Fahrenheit, and the apparatus disclosing no non-adjustable defects, the aircraft were shipped after one test flight to extreme height each. This was taking a chance, but it had to be done. The special apparatus involved was:—

1. An electrical heating circuit, the power being generated by 1,000-watt generator, designed to be air-driven, but driven direct from the engine. The gear to do this was provided by Messrs. Bristol.

This circuit heated the following:—The clothing, boots, gloves and goggles of both observers and pilots, with separate switches for each item and a special rheostat for the goggles.

The oxygen circuit between the oxygen control valves and the flow meter.

The three cameras, one vertical Williamson Eagle 3, the P14 and the Newman Sinclair cinema camera; the former, in addition to the heated jackets, having also an internal filament and a special heater for the cone. There were also special heated jackets for the reloads for the film cameras.

This circuit also provided the power for the motor driving the camera. The power was passed through a 12-volt accumulator swathed in felt as a protection against the extreme cold.

The total loads when all heating elements were in action were 1,060 watts, which was very near to the maximum permissible output.

The distribution of these loads being:—

Clothing of personnel, including goggles ...	560 watts.
Camera heating	340 ,,
Camera reloads	60 ,,
Camera operating	80 ,,
Oxygen heating	20 ,,

The maintenance of the voltage at the correct figure was essential to the proper working of the camera, and to the requisite heating of the apparatus. To insure this, a variable resistance, controlled by the observer, was inserted in the circuit to compensate for the different loads in the circuit and speed of the engine. This was the only important piece of apparatus other than the camera heating which showed up as requiring modification after the first test flight. In this circuit further safeguards were inserted against too high a voltage. They were an automatic cut-out trip switch and a fuse.

The other electrical problem we had to guess at was at what temperature the storage battery in the main circuit and the semi-dry battery in the telephone circuit would cease to function. We jacketed them with felt, and this proved sufficient, although had the generator failed, we had not much faith in the wet battery continuing to function for any useful length of time. In this contingency the orders were for the pilot and observer to switch off everything except the heating to oxygen goggles and camera, and make for home.

2. The oxygen circuit was laid out in duplicate in such a manner that the pilot controlled the main supply, but either pilot or observer could turn on the secondary or emergency supply in case of need.

The supply carried was 3,000 litres, 2,250 litres in the main and 750 litres in the auxiliary supply.

This supply was carried in four bottles weighing 14lbs. each at a pressure of 125 atmospheres. The bottles were made of Vickers Vibrac steel. A steel which tears, but does not shatter in an explosion.

It had been established that each man required eight litres a minute at the working height of 34,000 feet to remain efficient.

It was an over supply for the pilot, but probably slightly an under supply for a hard-working observer.

One of the defects in the design of the mask is that two-thirds of the oxygen supply is wasted, as the normal inspiratory period is only one-third of the total time, two-thirds being expiratory, and the system is such that the oxygen flows into the front end of the mask.

The oxygen flow meter was marked in 5,000 feet, and was kept at that reading above the actual height to insure that the highly stressed observer got sufficient oxygen to enable him to function. A long sustained over supply of oxygen can induce convulsions, but there was no risk of this occurring with the apparatus we used.

The oxygen masks and flexible piping caused us difficulty throughout the expedition, and require considerable modification before they can be said to be an efficient and reliable piece of equipment. In the form supplied to us, they are totally unsuited for an observer in active service conditions, and a great handicap to the efficiency of the pilot.

The importance of comfort to the airmen, and especially the observer or gunner, cannot be over-stressed in a consideration of his efficiency. The head equipment worn on these flights is so cumbersome as to approximate to a clumsy and badly weighted crusader's helmet. To appreciate the clarifying effect of such an apparatus on the mental faculties, I suggest that members of the audience should attempt to write a paper while wearing one. An adequate substitute would be to place a heavy bag over the head and then attempt to think clearly.

The need for oxygen at great height is undisputed, but certain factors as to this need are not generally known. Mountaineers or airmen, if they spent long periods at great height at frequent intervals, gradually alter the constitution of their blood by adding to the proportionate number of red corpuscles. In extreme cases, such as that of a mountaineer living at above 20,000 feet for several weeks, the number of these corpuscles is nearly doubled. This enables the blood to assimilate and make more use of the limited supply of oxygen available.

In America the Sperry Gyroscope Company wanted to ascertain by practical experiment the effect of height on unacclimatised individuals. They called for volunteers and obtained ten men of different physical make-ups, who consented to allow themselves to become unconscious. Having obtained the services of a doctor, equipped with oxygen apparatus, to succour and revive the passengers as they became unconscious, the aircraft took off and climbed to 23,000 feet. The first passenger became unconscious at 16,000 feet and the last at 22,000 feet, unconsciousness supervening in almost direct relation to their adiposity, the fattest going off first and the thinnest last.

We assumed that on the failure of the oxygen system, by holding the breath, consciousness could be retained for nearly a minute, or if attempting to breathe, for less than 30 seconds, at a height of 34,000 feet.

Painful shortage of oxygen was experienced by Mr. Bonnet over the summit of Everest, due to a partially broken oxygen pipe, the result of its being trodden on and wrenched. By myself in a test in England at 35,000 feet, due to a loose and ill-fitting oxygen mask.

The first sensations are quite definite, being pains in the knees, solar-plexus and heart, and if very severe, accompanied by physical sickness. In Bonnet's case, he was lucky to remain alive, and only did so because he retained sufficient thinking power to discover the break and wind his handkerchief around the partially severed tube, thus bringing the broken ends together. Doctors inform me that a shortage of oxygen, such as this, has a temporary if not a permanent effect on the brain power of the victim.

There were also two mild cases of lack of oxygen, both over the mountains. McIntyre, owing to the loss of the microphone from the front end of his mask, which he had knocked off by a movement of his head to watch his instruments, etc. Fortunately he quickly discovered this from the cold sensation on his lips and a slight feeling of a lack of oxygen. This was lucky, as he was over Everest at the time. He replaced it and held it on with his hand and, as we all know, got back to the aerodrome at Purnea.

In my case, I remained rather too long in the vicinity of Kangchenjunga and did not realise I was becoming stupid from a lack of oxygen until, on turning back, I realised I could not remember which of the courses I should take to return and at the same time to avoid violating the Nepalese border. I had written these courses down only two hours before. I was also too stupid to realise that I could quite properly have made use of my emergency supply. I presume the original inhibition against the use of the emergency supply, except in the case of real and sudden emergency, governed my mental processes in their condition of reduced mental efficiency.

In the War, I can quite well remember, after flying at great heights, my memory and mental responses became so dulled as to militate seriously against the value of the report on my return, but this condition had the advantage that it lessened the natural inclination to avoid anti-aircraft or enemy aircraft.

This latter effect was purely negative and could certainly not advantage the fighter.

On their return from both the Everest flights, I remember being much struck by the great contrast which existed between the appearances of the pilots and observers. The pilots looked much refreshed by their three-hour incursion into the higher altitudes. The observers, on the contrary, looked tired and done up. This difference was no doubt due to the fact that the observers had had to stand up in a temperature of 50 degrees below zero and in the slipstream (120 m.p.h.) to manipulate their heavy cameras (eighteen pounds in the case of the Newman-Sinclair). This and their constant movement to select the best objectives and reload their cameras, etc., must have inflicted a great strain on their heart action, particularly when it is remembered that they had to hold their cameras clear of the fuselage to avoid the transmission of vibration and were continually stooping and standing up as they changed or reloaded their cameras. A slipstream is also very tiring and this the pilots completely avoided by the good design of the Westland windscreen. The pilot really sat comfortably in still air, and as McIntyre proved on the second flight, had no need to wear goggles.

The reduced pressure to which human beings may be subjected without physical harm is not yet a matter of absolute knowledge. How long the internal organs and the blood system, etc., takes to be adjusted to a new external pressure has yet to become generally known. In the case of the flight over Everest the external pressure was reduced from about fifteen pounds per square inch to under five pounds. To resist the effects of this, muscles and arteries had to be in especially good condition. To ascertain if the personnel was fit for this they were tested in a vacuum tank at Farnborough in similar conditions to those experienced at a height of 37,000 feet.

The cameras used on these flights, in each aircraft, were:—

(*a*) A Williamson Eagle-three type, electrically controlled and operated automatic camera.

This camera utilised film and was equipped with an all-metal louvre shutter. It required external heating by heating jackets over both the body and cone and an internal heating element to prevent the film becoming stiff in the extreme cold. This hot wire element was protected by a mica filament, but involved a certain amount of anxiety as it was necessarily near to four pounds of nitrated film. One reload, also swathed in a heated jacket, was carried. This camera had a focal length of 5in. and a film exposure of 5in. by 5in. Length of the film is 125 feet which gives 140 exposures.

(*b*) A Newman-Sinclair 35 millimetre spring-driven cinema camera. This camera had a focal length of 3in. and, of course, used film; 1,200 feet of film per camera was carried. Each reload contained 200 feet. The cameras and the reloads had heated jackets. In some cases the heating proved insufficient; the reloads, due to the cold, crystallised and snapped. The second aircraft carried two of these cameras.

(*c*) A Williamson P-14-eight-inch focal length, 5in. by 4in. plate camera. This camera, using as it did a fabric shutter and being built up of different metals, was equipped with an internal filament and a jacket to maintain it at a sufficient temperature. Each aircraft carried one of these cameras.

(*d*) A Williamson Pistol-plate camera, focal length 2¼in., plate 3¼in. by 2¼in. It is all of one metal with metal louvre shutter. It had not, therefore, to be heated. The first aircraft, only, carried one of these cameras.

(*e*) A small ciné Kodak, carried only by the first aircraft.

In the preparations of tests and the actual flights the camera gave us more anxiety than any other part of our apparatus. Owing to the hurry of our preparations we did not get the cameras ready in time to give them a thorough test in the freezing chamber, prior to the actual height test in England. Consequently, we had to do our final test under simulated rather than actual conditions. It was a matter of great difficulty to get these conditions severe enough for a long enough period, as the temperatures which we were aiming at were approximately 80 degrees Fahrenheit below zero. The difficulties caused by dust and the infiltration of the very bright light experienced were overcome by care in maintenance and operation. The failure of the vertical photographs on the first flight was mainly caused by dust haze, but may in some part have been due to the wrong exposure for the day. The filters used were Alpha K-1 and K-2.

The infra-red photographs were obtained in the face of considerable difficulties because of the size of the camera used. The main flights being the primary objective, the infra-red camera could not be permanently maintained in position until these flights had been completed, and each time a flight was contemplated it took some hours to rig it up. The camera, of 25-inch focal length, was slung in the fore and aft line of the PV. III in the approximate position intended for the torpedo which the aircraft was originally designed to carry. It was held in this position by rubber suspension pressing it into place against rubber and horsehair pads supported on the fuselage. It was aligned at an angle of 6° below the horizontal to allow for the climbing angle, etc. It had an improvised lens cover to keep the lens clean.

The method of operation involved the pilot pointing the aircraft at the objective by the use of an improvised sighting line, the necessary signals being passed between the observer and the pilot by a strong communication cord. The observer worked under real difficulties as he had to lie on his face and reach out each time he had to reload the camera and uncover the lens preparatory to another shot. The photographs obtained by Colonel Blacker and Flying Officer Ellison were surprisingly good and free from vibrational effects, considering the length of the exposure, one-sixtieth of a second, and the method of suspension and the fact that they had had no previous practice.

I will not comment on the flight out to India more than to remark that it was undertaken for three reasons:—

(1) We had done everything in such a hurry in England that we had to stay after the two big aircraft had been shipped out to get things straight before we left.

(2) We required small aircraft for cloud reconnaissance and to discover the right time of day to make our one permitted flight over Everest. We also required them for communication purposes in India, and it was the cheapest way of getting them and the personnel out and home.

(3) It was essential to keep the personnel in flying practice and there is no better method than by continually landing on previously unknown aerodromes.

We did not have blind flying equipment in two out of the three small aircraft and this we had reason to regret in the dust storms in which we became involved going out and coming home.

We had a great advantage in that our aircraft were disembarked, erected and tested at the R.A.F. depot in Karachi. The flight across India had been carefully prepared for and it was therefore uneventful except for one of the small aircraft. A Fox Moth returning from a preliminary reconnaissance of the route across India stayed at Allahabad. It was picketed out and while the personnel were obtaining the services of a police guard a violent storm suddenly broke and reft it from its moorings and smashed it most completely. In India hangars are necessities far more than in other and wetter countries where the weather is neither so violent or sudden in its changes. The difficulties at the base, thanks to the excellent preparations made for us, were minimised. There was, of course, heat, but this had been expected and therefore forestalled. The unexpected was the very insidious and all-pervading dust and the strength and continuance of the wind at height. The dust was dealt with by daily testing and cleaning, but in the first flight over Everest and Kangchenjunga it was met up to a height of 19,000 feet.

The behaviour and maintenance of aircraft and engines was good and easy.

The Westland aircraft gave no trouble, but the insidious dust had to be carefully guarded against by rigorous daily cleansing; the zip fastened fabric panels in the fuselage were invaluable from this point of view.

The hinge pins showed considerable wear and larger surfaces for prolonged use would be necessary. The anti-freezing oil functioned satisfactorily at high altitudes.

The tropical finish wooden propellers were satisfactory. They were very carefully looked after and had often to be tightened, and after a month's use caused slight vibration, probably due to warping.

The small wooden aircraft were a continual source of nuisance owing to the insistent need for tightening up against wood shrinkage.

The Bristol Pegasus engines, I.S. III, gave us no trouble at all. They gave 490 h.p. at 2,000 r.p.m. at ground level (no over-ride control for take-off was fitted); 550 h.p. at the rated altitude of 11,000-13,000 feet, and fell off to 235 h.p. at 2,080 r.p.m. at 35,000 feet. The temperatures of the cylinders at different heights in England and India and as to how far the reduction of the cooling properties of thin air would be compensated for by the reduction of horse-power at heights was an interesting problem. Particularly so, as it was not known how far temperature fell with height in India. Figures obtained in England for the Pegasus were quite satisfactory, 219°C. being the highest temperature obtained on a full power maximum angle climb. A figure of about 215°C. at full power and maximum climbing angle is, I understand, accepted for air-cooled engines required for all climates. Engines behaving thus have been proved to give satisfactory service and a temperature of about 170°C. under cruising conditions.

The effect of reduction in air density is most pronounced in supercharged engines, and this difficulty increases as the height to which rated boost is maintained increases. Because with supercharged engines the power and therefore heat increases with altitude up to the rated altitudes and the cooling properties of the air decreases more rapidly than the drop in temperature with height.

With a water-cooled engine this difficulty is accentuated owing to the limitations of working temperature, the low temperature difference possible and the falling boiling temperature with height.

We used Townend rings and these, reducing as they do the indicated air speed by some 40-60 per cent., added to our problem. Messrs. Bristol have met this difficulty by using close pitch fins cut from solid steel forgings and thus increased the fin area by 66 per cent.

Neither the Potts oil coolers or the barometric throttle control gave any trouble.

The dust and heat apparently caused no trouble to the engines except for shrinkage in the wooden propellers and fibre washers.

Wooden propellers were used, not only because they were cheaper, but also several different models could be quickly built and tried, and furthermore, they are notoriously kinder to the engine.

There was no great advantage to be gained by using variable pitch propellers, because our power was ample for our task and their use would have added one additional anxiety.

The oil and fuel used were respectively Wakefield Aero C. and Shell's special mixture; both, as was to be expected, gave complete satisfaction.

The fuel was 80 octane value and composed of 85 per cent. aviation spirit, benzol 15 per cent., with 1.53 c.c. per gallon of ethyl fluid 65.3 per cent. pure T.E.L. We could not use a greater percentage of benzol because of its low freezing temperature.

We used no spares and our K.L.G. plugs gave no trouble at all.

The oil tank vent pipes were welded to the exhaust tail pipes to prevent the vent freezing.

The fuel vents were faced rearwards within a cone facing forwards to generate a positive suction and so prevent freezing.

The latest Bristol Pegasus IV, I understand, gives a considerably higher performance than the one we used, 50 h.p. more at 35,000 feet. Therefore if anyone wants to continue our investigations they have yet more power available.

The meteorological facilities, organised by the Director of Meteorology, India, were excellent. We had two stations, one at Purnea and one at Darjeeling, specially devoted to our interests, and we had the forecast from the whole meteorological organisation of India co-ordinated at Calcutta and passed to us daily at 8.30 p.m.

For the first twelve days we were there, and we only had twenty-three available before April the 15th after we arrived in Purnea, the wind strength varied from between seventy-five to one hundred and twenty-five miles an hour at our operational height.

We had been advised not to attempt the flight, by the authorities in England, unless the wind dropped to thirty miles an hour. We soon came to the conclusion that this wise and cautious advice would have to be disregarded. Our meteorologist, Mr. Gupta, an Indian, said that indications showed that the wind rose or fell in about ten-day cycles and that it was unlikely that the wind would get as low as we hoped. This forecast proved very correct. Three days before the flight he had prophesied correctly, based on meteorology, and I think after also consulting the astrologers, that Monday, April 3rd, would be the most suitable day. On Sunday, April 2nd, for the first time, he was able to predict a moderate wind for the morning of fifty to fifty-five miles an hour at 33,000 feet;

in actual fact it was about fifty-seven miles an hour above Purnea and probably approximately the same over Everest at the same height.

After carefully working out our fuel and oxygen consumption, and after allowing a good safety margin, we had come to the conclusion in England that we could only rely upon about twenty minutes at a maximum in the vicinity of Everest's summit. Taking this as a basis, we had consulted Mr. Hinks, of the Royal Geographical Society, the School of Photography, and Colonel MacLeod of the War Office, and planned as follows:—

To equip each aircraft with a vertical survey automatic camera and that the observer in one aircraft should primarily devote himself to obliques and the observer in the other to cinema photography.

That we should attempt to take a double vertical strip into and out from the summit by both aircrafts, which should include as many triangulated points as possible at the commencement and termination of each strip. Two film rolls with one hundred and forty exposures per film roll was calculated to be adequate to this task, allowing for sixty per cent. overlaps longitudinally and thirty per cent. overlaps laterally.

That it would be desirable to take photographs obliquely of the country each side of the vertical strip with a view to extending the area mapped if such a thing proved possible, and at the same time that the cinema operator should bear in mind that some of his work might conceivably be used for mapping.

Mr. Hinks of the R.G.S. was, of course, very interested in the verticals, but also laid great stress on the possible importance of the obliques—he foresaw all sorts of uses for them. It is interesting in the after event to realise that had it not been for the excellence of the obliques it might have been impossible to tie and plot the verticals.

It was realised that neither the obliques nor cinema photographs could give anything but rough approximation in the extension of the map plotted from the verticals. This possibility has not yet been tested out. An amazing coincidence on the second flight, which enabled the latter half of McIntyre's photographs to be mosaiced, was that his and Clydesdale's last consecutive photographs finished off on the same spot.

I will not enlarge on the photographic aspect as it has been very fully dealt with in the R.G.S. Journal of July, 1933, and February, 1934. I will merely remark that our preparations to meet the unusual conditions with which we were faced only failed in two minor respects. Dust caused us more trouble than we had expected. The reloads for the two film type cameras and the vertical camera were insufficiently heated. We should have planned better if we had given less heat to the pilot and more to the reloads, but we could not foresee this.

Under the unusual circumstances I consider the survey results obtained, although not strictly accurate from a mapping point of view, and only of real value because of the immaculate work of Lieutenant Salt and his assistants, have at the same time proved that continuous overlapping strips of unknown country such as this can be successfully plotted. I would also say that, in my opinion, both the pilots and observers did remarkably well to obtain the results they did, in view of the tremendous conditions they were faced with, flying over such an unusual terrain in a cross wind of over 100 m.p.h.

The training for this flight was accomplished under difficulties. Recent flying practice was insured by flying out to India. The accomplishment of the very difficult survey task set to the two Everest pilots was trained for in England and again in India. The idea being that the two aircraft should fly a wide distance apart when they were over the low ground, approximately at 11,000 feet, at the commencement and termination of the flight and gradually close in as they approached the summit. McIntyre devised a small instrument with which he practised in England, but he was set an exceedingly difficult task in attempting to fly at a predetermined distance away from Clydesdale and then gradually

to close in. When it is remembered that they were bound to have a cross wind of largely unknown strength, flying up the Arun Valley, the full difficulties can be imagined. However, this was the plan and it was practised in the air.

Otherwise, the training of the four pilots and three observers in the use of their rather unusual instrument, owing to the limited supplies of oxygen, had to be largely based on a form of question and answer training on the ground. This was carried out at Karachi. All conceivable eventualities were posed and an almost immediate answer demanded before this part of the training was regarded as complete. The value of this form of training is emphasised by the generally recognised fact that men's reasoning powers do not function so smoothly under conditions of noise and nervous stress, whereas their trained reactions, except in the case of shock, appear to behave quite normally under such conditions.

The useful practical lessons gained from the actual flights, two over Everest and one over Kangchenjunga, were in my opinion as follows:—

1. That air survey over the highest mountains is practicable.

2. That skilled work can be done for long periods by men breathing oxygen at over 30,000 feet.

3. When flying near the ceiling in the vicinity of very high mountains to maintain height it is essential for the leading pilot to disregard the mountains and closely observe and fly by his instruments.

4. The second aircraft should have the better performance.

5. That in planning out a continuous strip to the summit of a high mountain, if the approach is made upwind, it is probable that the aircraft, unless several thousand feet above the summit, will be swept down by the overfall of wind, caused by the air which has been driven up after crossing the summit, seeking its own level again.

6. That the air immediately over high peaks may be quite smooth, even in very high winds, to probably within a few hundred feet of the summit.

7. That exceedingly dangerous transverse disturbances may exist on the lee and weather side of and close to high mountains at approximately the level of the summit or summits. The effect in the instance experienced on the aircraft was to roll it back and forth laterally on its fore and aft axis and at the same time rock the same axis back and forth directionally, but with little effect on the looping plane. It appeared to be a disturbance rather in the nature of a breaking crest of a wave, if such a thing can be said to exist in a non-viscous fluid such as air. There was no sudden drop and the accelerometer registered a reading of only 2.8g.; 5.6g. has been measured in America.

The next time Everest is flown over in a high wind photographs of the plume may disclose how air behaves in such circumstances, although the behaviour of air in the lee of such a sharp crest as Everest may be totally different to its behaviour in the lee of a great surface, such as the crest of Kangchenjunga, where the disturbances in question were experienced. This investigation could no doubt be simplified by the use of smoke clouds released to windward of the peaks under investigation.

The most likely explanation of the plume of Everest is that the high winds sweeping across its sharp summit draw the fine crystals lying on the south-east face into the air. These ice crystals are probably the deposits caused by the condensation of the warm air rising up from what may be called a sun bowl at the base. Makalu has not a similar plume, probably because the lee side of the actual crest is too steep for snow to lie on.

8. That the pilot, provided he is properly enclosed by a good windscreen, can be very comfortable and need not wear goggles unless he is going to look over the side of the aeroplane.

9. That the observer should have his oxygen and telephone equipment fitted and introduced into his clothing in such a manner as not to handicap his freedom of movement, as was the case with the gear used by our expedition.

10. That the present oxygen equipment is clumsy and inefficient and requires complete redesign from the panel to the pilot or observer. The bottle, flowmeter and pressure gauge and heating elements were all quite efficient however.

11. That exposures longer than one-sixtieth sec. can probably be made from aircraft without showing vibration, always providing the cameras are mounted with this in view.

Finally, I would like to emphasise that the principle on which this expedition was prepared and carried out was: To seek and make use of all available experience, but before making a final decision a test was made by each responsible individual concerned to obtain his own personal experience.

In my opinion, the importance of the principle that all who have to make important decisions or who are in positions of great authority in aviation should themselves try out personally anything really important on which they have to adjudicate is at present vital to the safe and sure progress of military and civil aviation. If they are not able to do this then they are not fitted to hold the position of authority.

Human imagination without experience is an insufficient guide and personal risk should not be allowed to stand in the way of obtaining personal experience. Not to wish to go thus far shows a lack of a sense of genuine responsibility.

At its present state of development aviation requires that only the real enthusiast should reign in positions of authority. The man who is there merely to earn his bread and butter is not the right type. There are two billion people in the world, and if amongst these two billion there is an insufficient supply of men or women with the right temperament, and that is the flying temperament as well as the technical or professional training, to fill all the positions of authority in aviation, then the world is not yet ready for this development.

Air-Commodore FELLOWES, at the conclusion of his lecture, added: This is the oldest aeronautical society in the world, and because this is so, I should like to speak for a few more minutes on a matter which has been near my heart for many years. I am doing what many, possibly, may think wrong, but I personally think to be right; it is to expose what I consider is a veritable canker in the control of British aviation.

Our attitude of mind in England can be epitomised by a story. An American lady went to a travel office because she wanted to travel to Paris from Switzerland by air, and she asked the clerk-in-charge about the possibilities of flying. He was most enthusiastic and said it was the safest, cleanest and most delightful way of going about. She said: "Oh, you are so enthusiastic, you must have flown a lot." The reply was: "Oh, no, I am responsible for three small children."

That attitude of mind is not a healthy one. The people in America regard flying as quite a normal thing. You hear fellows talking about going somewhere, and they ask: "Are you going by car, train or aeroplane?" That is the sort of question one would naturally ask there, and civil aviation there has leapt ahead of what we have done here, though they started long after us. All the people concerned with the direction of aviation in America are themselves pilots. This even goes as far as the Aircraft Inspection Department. Vice-Presidents and heads of firms concerned with transport, engine design and aeroplane design, and many members of their staffs, are pilots. When I went to see the Douglas machine I met Mr. Andrews and Mr. Leroy, who are pilots for the Trans-Continental and Western Air Company; one of them had flown 10,350-odd hours, and the other 6,500 hours. I asked the question: "Is it a fair statement to say that any pilot, however experienced, either learns or re-learns some useful lesson every time he goes up?" Andrews, who had flown 10,350 hours, said: "Yes, that is an absolutely fair statement; and what is more, he

cannot pass on that experience to any other individual unless that other individual has had great recent experience himself."

Again, I met a Mr. Breakennidge who is 63 years old and who wears spectacles which appear to be about a quarter of an inch thick, and to my astonishment he said: "I learned to fly a few years ago, and I have flown for 600 hours; I go everywhere by air." He is a very busy business man. He said: "I go up once a week and do aerobatic stunts." When I asked him what he did, he said: "I do a roll or a loop, or something like that." He is 63, he is a brother of Lindbergh's lawyer, and he was actually taught to fly in the first instance by Lindbergh.

People who do not fly don't know what they don't know! In my opinion, the finest flying personnel in the world live in this country, but the reason for our backward state of mind here can be traced to one order, which was given at the beginning of the war, "that Squadron Leaders and above need not cross the lines." That order was given on a false principle, which is demonstrably false so long as human beings are mortal. It was given on the principle of indispensability. The result was—I regret to say, in some cases though perhaps not in many—this situation appealed to people, and they went over there and never crossed the lines, and soon gave up flying as pilots. I think they would have been serving the country's purpose better if they had crossed the lines—not to get shot down, as many people may say, but to gain experience. If they had done so, many valuable and wonderful young lives would have been spared, because the inexperienced commanders could not know what experience was necessary to a man before he could be usefully sent across the lines. Many young men simply went across and made expensive and wonderful targets, trained and paid for by us, just for the German experts to practice on. And that is a fact. As a result, not only did we suffer the loss of many valuable lives, but we also raised the enemy morale.

This must not happen again; and the only way to ensure that it does not happen again is to make a rule that everybody in a position of authority has to fly himself—and they can all do it if they want to. It is the spirit of the man, and not his physical attributes, which decides whether he can fly.

I will draw an analogy from nature. The emu is a bird which has embryo wings, and no doubt he has impressed his fellows in the forest that he can fly; he flaps his embryo wings, but because he does not send his energies into his wings they go to his claws, and perhaps his brain. They have wings of clay and claws of iron.

The people who to a large extent control flying in this country have an iron grip on what they hold, and it will take a long time to get rid of them. But we have to clean up the situation in this country. These pseudo great airmen will say: "This is all nonsense; anybody who has any brains never flies." This idea has such a firm grip in aviation circles that a first-class young fellow said to me: "I cannot get any job worth having. Everybody thinks that because I fly I am a fool; I am going to stop flying." I replied: "No, this false idea must break some time." And I hope it will be soon.

I am sure you all agree that air power is the one thing in regard to which it is necessary for us to be uppermost if we are to preserve our Empire (Hear, hear), and I think this dead hand of ignorance—I call it deliberately a dead hand of ignorance—should be removed, because non-fliers don't know what they don't know. Many of them are delightful and charming people, but they don't know that they don't know. Why should a great nation like this be satisfied with a sort of monthly guessing competition going on between these people in control of our aviation? In America they sit together and talk from real and absolute knowledge—people such as Lindbergh are in control of their technical development, and that is why they are leaping ahead.

Some people might call this pusillanimous ignorance, but it is not that; it is purely the result of a lack of imagination, and I do not feel we can look our brother great nations in the face until we are controlled by intelligent airmen, and not chairmen. There are plenty of airmen with the right qualifications, so why shouldn't we put them in control and thus secure a right and knowledgeable direction, and remove what I seriously say is a danger to the British Empire?

Following the lecture, some very fine aerial photographs of Everest and the surrounding peaks and glaciers were exhibited on the screen by Air-Commodore Fellowes and Colonel Blacker (the Chief Observer, who was responsible for many of the photographs).

Some of the photographs shown served to emphasise the difficulties to be overcome by the climbing expedition to Everest; Colonel Blacker said that the members of the Houston-Everest expedition were perhaps better able than anyone else to pay tribute to the climbing expedition, and they very gladly did so.

Discussion

Air-Vice-Marshal A. E. Borton, C.B., C.M.G., D.S.O., A.F.C.: He voiced the thanks of the meeting to Air-Commodore Fellowes for his wholly admirable explanation of the work of the expedition. One was tremendously impressed by the wealth of detail to which thought had had to be given, from the time when Lady Houston's public-spirited generosity had made the expedition possible until the expedition had started, and by the wonderful and unostentatious efficiency with which the whole of the work was carried out. Perhaps it was in accordance with that absence of ostentation that Air-Commodore Fellowes had omitted to state that the leader of the expedition, naturally, and without any fuss, went to India by air, and had arrived there practically according to programme. One was also tremendously impressed by the marvellous team work which must have been displayed by the whole of the expedition, and at the way in which they had put up with the inevitable delays—particularly when one knew how anxious they were to complete the work. Colonel Blacker, when explaining the photographs, had paid a particularly nice tribute to the climbing expedition to Everest, and everyone would agree with him; but, at the same time, one could not help feeling that the members of the Houston-Everest expedition could claim credit for a truly magnificent achievement, which would go down to history as one of the finest of our time.

The remarks made by Air-Commodore Fellowes at the conclusion of his lecture might possibly be of a rather controversial nature! He had recently returned from America—it would be ridiculous for them not to take advantage of the wealth of experience gained there—and his remarks were worthy of very serious consideration by all who had the welfare of aviation at heart.

Mr. H. E. Wimperis (Vice-President) (Director of Scientific Research, Air Ministry): He was glad of the opportunity to join in the tribute to the splendid work done by the expedition, under his old friend Air-Commodore Fellowes. When he had first learned that Air-Commodore Fellowes was to be in charge he had felt very happy about the final result; having had the pleasure of knowing him for the last 20 years, one appreciated his sterling qualities, his ability to knit people together—and even to knit instruments and gears together—in order that the whole should work harmoniously. The instruments used seemed to have served well, apart from one exception; the helmet and tubing of the oxygen mask had given rise to difficulties. Air-Commodore Fellowes would be glad to know that the replacement of all the equipment he had spoken of rather adversely was under trial by the Service Squadrons to which it would be issued when approved.

With regard to the scientific results of the expedition, one had been naturally curious to know what kind of atmospheric turbulence might exist near a mountain so exceedingly lofty as Everest. An accelerometer was used, to measure the bumpiness of the bumps, and the highest reading obtained was 2.8g., which Air-Commodore Fellowes regarded as rather low. In point of fact, however, investigations which the Air Ministry had been making during recent years indicated that that figure was rather above the average that one might expect in bad weather conditions. Reference was made in the lecture to a reading twice as high—5.6g.—having been obtained in America. He did not know whether that included a discount to be allowed for the enthusiasm of our cousins in America! He had previously heard of a reading of 11.2g. having been obtained in the U.S.A., but that was not due to atmospheric disturbances alone, however, but also to the, involuntary, aerobatic actions of the pilot—who was very sorry for it afterwards.

Finally, Mr. Wimperis paid tribute to the beauty of the photographs exhibited, and also to the amazing courage of those who obviously must have flown very close to rocky precipices and icy slopes in order to get the photographs, in spite of the knowledge that if anything had gone wrong with the engines the results would have been "unpleasant." They owed a deep meed of admiration to Air-Commodore Fellowes and his gallant crew.

Dr. G. C. Simpson (Director, Meteorological Office): He would like to comment upon the lecturer's explanation that the plume of Everest consisted of ice crystals blown from the top of the mountain, and to put forward an alternative. Having seen a considerable amount of snow drift, though not necessarily at the top of Everest, he was quite certain that the tremendous volume of the plume of Everest could not be filled with anything which had drifted from the surface. In the first slide on which the plume was seen it had extended for, he believed, more than 100 miles, and when one considered the great volume of air to be filled one would conclude that it was unlikely that it could be filled with snow from the top of the mountain. The explanation given by meteorologists was very straightforward. It was that as the air blew across the top of the mountain it had to rise, and in some conditions this caused cloud. Further on the lee side of the mountain a very great vortex was set up, in which the air near to the surface of the mountain on the lee side was drawn up from very low down the mountain side, and it must produce fog and cloud towards the top. This air, having been brought up from below, was warm and moist and as a result of adiabatic expansion cloud was formed which got into the stream of air and and was blown from the top of the mountain, forming a big plume. In most of the photographs exhibited there could be seen the great mass of cloud just below the summit of the mountain, on the lee side.

Dr. Simpson derived considerable pleasure from the fact that meteorologists were able to help the expedition, and said he was quite sure that some of the results obtained would be of great help to them in their meteorological studies.

Sir Ernest Petter (Chairman of the Westland Company): He recalled the activities at the Westland works just over a year ago in getting the machines ready for the expedition, and added that those responsible for the works had benefited very much from their experience at that time. He personally had learned at least one lesson—that a great many people can work slowly with satisfactory results, and a great many can work quickly but not accurately; but the test was to be able to work quickly and accurately and thereby achieve such a result as had been recorded in the lecture. He remembered being present at one or two of the discussions at which decisions which Air-Commodore Fellowes had referred to as speculative had had to be taken; and he remembered also the anxiety which was experienced with regard to the shipment of the two machines. Air-Commodore Fellowes had said that when it was stipulated that he should be present at the loading and at the unloading he did not know what

on earth it was thought that he could do. Well, those responsible for the stipulation had not thought that he could do anything, but they knew that if he were there nothing untoward would happen.

In conclusion, Sir Ernest said that he was a chairman rather than an airman, and the remarks of Air-Commodore Fellowes had given him much to think about.

A SPEAKER: What period of time had the expedition occupied?

The CHAIRMAN: He would like to refer to the generosity of Lady Houston. Remarkable as had been the work of the expedition, it could not have been done unless somebody was prepared to foot the bill. Therefore, he had taken the liberty, at the commencement of the meeting, to send to Lady Houston, who was very seriously ill, a telegram of good wishes and hopes for her recovery. It was sent in the name of the Royal Aeronautical Society and all present at the meeting. Besides making the expedition possible, Lady Houston had done a great deal for aviation in other directions.

There was much to be learned from a study of the lecture, and also from the subsequent remarks of Air-Commodore Fellowes; they were made very appropriately, and the Chairman agreed fundamentally with them. Presumably they would soon be able to see the report of Lord Gorell's Committee, and the remarks of Air-Commodore Fellowes gave much food for thought.

REPLY TO DISCUSSION

He took the opportunity to express his personal thanks to Lord Sempill for having presided. He recalled that Lord Sempill had been intimately in touch with the whole organisation of the expedition and had rendered great help; and he had taken charge of the organisation here while the expedition was in India. All present at the meeting would wish to congratulate him on his truly wonderful recovery from the terrible accident which had befallen him in America. (Hear, hear.)

Commenting on the remarks of Mr. Wimperis concerning the accelerometer reading of 5.6g., obtained in America, he said it was obtained by Major Dolittle, flying at 180 miles per hour, when he had run into very bad weather. When the result was reported to the authorities in Washington they would not believe him. There were two accelerometers on the machine, however, one of which was sealed, and when that was opened it was found that the reading was practically the same. So that the figure of 5.6g. was verified.

Replying to the question as to how long the work in connection with the expedition occupied, he said that tremendous work was done by three people, from about the beginning of 1932 until November of that year, in collecting and sifting data, tackling people to collect money and assembling the various technical details. It was not until November 16th, 1932, that the money was obtained so that things could actually be paid for. The expedition occupied exactly six months from that date until the members had reached home, on May 16th, 1933. The preparations in England had occupied only two and a half months, up to the time the aircraft were shipped, and that was the strenuous period referred to by the Chairman of the Westland works, who had been extremely modest in what he had said about the extraordinary efficiency there. They had never had to alter a single thing they had put into the aircraft, except to make a slight adjustment on the variable resistance.

Dealing with the remarks of Dr. Simpson, he said, with the utmost humility, that the reason why he did not understand Dr. Simpson's explanation of the plume—and it was also the reason why he had tentatively put forward the explanation given in the lecture, and which was probably wrong—was that

Makalu had not a plume. It might be that it was volcanic in origin, but he had not cared to suggest that. He could not understand how the fact that Makalu had not a plume conformed with Dr. Simpson's explanation.

Dr. SIMPSON: He did not know the surroundings of Makalu, but he imagined that the contour of the land was such that the eddy could not go sufficiently far down to draw up the warm atmosphere.

Air-Commodore FELLOWES: He believed that was so, and he appealed to Colonel Blacker for confirmation.

Colonel BLACKER: He agreed that it was, so far as Makalu was concerned; but there were many others!

THE METEOROLOGY OF INDIA*

BY

J. H. FIELD, C.S.I., M.A.

Late Director-General of Observatories, India

In an interesting paper on the meteorology of India read before the Society in 1925, Sir Gilbert Walker gave a comprehensive account of the main elements of climate which affect the industrial and social well-being of the country, and dealt with the great question of seasonal weather forecasting, on which he has become the chief authority. I propose to-day to take up some of the newer means of dealing with Indian problems, and to add the consideration of a fresh item, the safeguarding of international aviation.

From the earliest days of the Weather Department the duty of warning for cyclones at sea and floods on land has been a strong interest, and a high standard of success has ruled for many years. The first signs of coming storm development at sea are watched at the several warning headquarters, and when the storm has been actually formed, its position and strength and its direction of travel can usually be rightly judged and broadcast. And now, within the last two or three years, a new and unlooked-for aid in this work has sprung to notice, for seismographs have been found to respond to the periodic pressures transmitted to the sea-bed from the waves at the surface, and, when a cyclone exists, to show a record which is quite distinctive.

A seismograph of normal sensitivity is never at rest; the pen, whether a mechanical marker on smoked paper or a ray of light recording on a photographic strip, is continually answering to minute vibrations in the ground and to small changes in the instrument zero due to variations of temperature in its neighbourhood. These disturbances of the record have commonly been regarded as blemishes, since they tend to mask the seismograph's real function of analysing earthquakes; but from time to time observers have suggested that some connection might exist between them and the roughness of adjacent seas.

A few years ago this question was gone into by Dr. S. K. Banerji, Director of the Colaba Observatory, working with a Milne-Shaw instrument in Bombay. He removed as far as possible all causes of local disturbance by placing his seismograph in a room well below ground level and with a constant temperature control, and then reduced its sensitivity until it gave a clean zero line untroubled by ground tremors due to local winds except when those winds were stronger than 20 miles an hour. With this done, he found that, apart from the records of genuine earthquakes, the tremors affecting his instrument were confined to three sources—local rough weather, monsoon winds at sea, and storms or cyclones in the Arabian Sea and Bay of Bengal; and, further, that he was able to distinguish clearly between these three sources by the character of the records they produced. Quivers from local rough weather had markedly long periods, 10 to 30 seconds; monsoon winds at sea gave a steady background of uniform tremors, with periods lying between 4 and 10 seconds; but cyclones at sea, even at 1,000 miles distance, showed vibrations with the unmistakable feature of pulsation in amplitude, due to the amalgamation of the steady monsoon tremors with the more violent shakings of longer period from the storm area itself. Fig. 1 shows an assem-

* Paper read before the Indian Section, Royal Society of Arts, on April 13th, 1934, and reprinted by kind permission of the Society and the Author.

blage of strips cut from seismograph records of various dates, of a few minutes' duration each; on the left-hand diagram strips 1 and 2 show the uniform tremors which result from a strong monsoon at sea without further disturbance; strips 3 and 13 are from two far distant storms (actually in the Bay of Bengal), and strip 12 from a nearer storm in the Arabian Sea. The pulsing in amplitude of 3, 12 and 13 is obvious, and its absence is clear in 1 and 2. On the right-hand diagram is shown the effect of strong local breezes alone, and these records have the longer periods 10 to 30 seconds. The advantage of the precaution in removing the seismograph from surface level (strips 8 to 10) to well below ground (strips 1 to 7) is seen at once in the comparative cleanness of the zero line in the latter records.

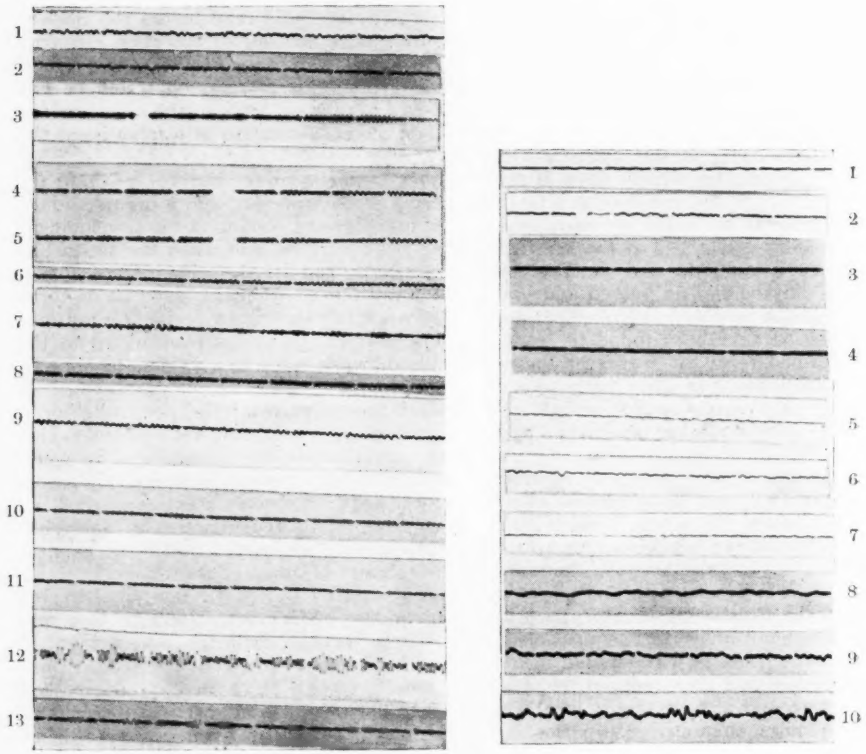


FIG. 1.*

Right-hand Diagram: Seismograph Records in Strong Local Breezes.
Strips 1 to 7, Instrument in Room under Ground.
Strips 8 to 10, Instrument in Ground Level Room.
Left-hand Diagram: Instrument in Room under Ground.
Strips 1, 2 and 4 to 11, Strong Monsoon at Sea.
Strips 3, 13, Cyclones in Bay of Bengal.
Strip 12, Cyclone in Arabian Sea.

* Reproduced by courtesy of the Royal Society from *Phil. Trans. A.* 29, *pp.* 287-328, *Microseisms associated with disturbed weather in the Indian seas.* By Sudhansu Kumar Banerji, D.Sc.

The magnification between the actual ground movement and that of the recording light beam in this instrument was 250, so that the amplitude of the tremors is exceedingly small compared with that in even a mild shock of earthquake. In the Arabian Sea storm (strip 12) the amplitude of motion was 8 microns from the position of rest, and in that of the Bay of Bengal 2½ microns; so that, as the micron is one-millionth of a metre, the ground movement at Bombay given by the latter storm amounted, in more everyday units, to one ten-thousandth of an inch. In spite of the minuteness of the vibration record at Bombay, the storm centre, then 600 miles distant, was already beginning a career of wild havoc at Nellore.

To come down to the practical effects of this use of the seismograph I may quote Dr. Banerji's words in a Royal Society's paper of 1930:—

> "The identification of the microseisms associated with storms throws open to the meteorologist a new method of recording their existence. . . . Whenever the presence of this type of microseism can be recognised in the record, it can be looked upon with confidence as indicating the existence of a storm. The information is thus a valuable aid to the forecaster, particularly when the indications regarding the existence of a storm from the usual meteorological sources are meagre."

And Sir Gilbert Walker has been reminding me of his own experience in June, 1907, when he had to warn Karachi to hold up outgoing shipping on account of a severe cyclone which was then approaching. The warning was well-timed, and undoubtedly saved a disaster, but when, later in the same month, he repeated his action for a second storm the danger was over-estimated and shipping was held up with less reason. He permits me to mention that in his present view the indications of a seismograph, if they had been understood at that time and available, might well have moderated his action on the second occasion.

A seismograph has hitherto had no purpose more practical or money-making than pure research, for no one can pretend that it can foretell an earthquake or offer any comparable service. But here we suddenly have an instance, like so many that have emerged in the past, of the intimate bond between pure research and a most practical need of common life. Such cases offer a strong argument for liberal treatment of a scientific department under Government in regard to budgetary means to carry on research.

But the meteorologist finds more interest in observations above the ground than in those under it, and I may break away now to consider what he has been busy over in recent years in the upper atmosphere. I may recall that in 1912 there was begun in India a programme of research into the characters of upper winds, and that this work has since shown continuous and vigorous growth. In those earliest days there were two main objects in view: to prepare for the interests of coming aviation by exploring the wind currents of the middle air up to five miles above ground, measuring their strengths, directions and thicknesses by means of small pilot balloons; and, secondly, to explore with recording instruments carried by larger balloons the whole body of air up to the greatest accessible heights, in regard to pressure, temperature and humidity, in the interests of pure and applied science.

For the first of these aims, the examination of the middle air, the small rubber pilot balloons are filled with hydrogen and set free, to rise steadily and drift with the wind; they are kept under observation by two theodolites at the two ends of a measured base line, and their movements give by calculation exact figures of wind distribution up to the points where the balloons disappear. But in those days the conditions of working in India were difficult and crude, for money resources were meagre, and the existing local means had to be moulded to the new purposes wherever possible. It had been found impracticable to import ready-made balloons of rubber in serviceable condition, and another material had

to be sought. After many trials the choice fell on thin gutta-percha tissue, and for years we had to make day by day all the balloons required for use. Nowadays the difficulty has disappeared, for the world demand for rubber balloons is enormous and the product is satisfactory. And so, also, with the hydrogen gas required to fill the balloons. As first made in Agra Observatory it was from old zinc scrap and discarded sulphuric acid bought up cheaply, and only later was a small electrolytic gas plant bought and put into use with a high-pressure pump to compress the gas into cylinders for transport. Yet during the war Agra was able to meet demands for observers and equipment in connection with gunnery practice as affected by upper wind currents, and to supply Iraq with compressed hydrogen, theodolites and balloons for use in the field, while still carrying on a skeleton service of its original work within Indian boundaries.

By 1919 the long foreseen demand by aviation for normal figures of air currents, their strengths, directions and thicknesses, had begun to come forward, and the Weather Department was by then ready to supply averages of several years for three stations in north India, and for shorter periods to cover the whole range from the Frontier eastwards to the coast of Burma. But the work was slow, and its daily results were not yet prompt or extensive enough to help the official meteorologist in his daily routine of forecasting, so that, even as late as 1924, he had in the main to be content with ground-level observations as his working material, with some little help from the appearance and movement of any clouds that were reported. His work in those days lay chiefly with daily weather reports and forecasts, seasonal forecasts, such as for a coming monsoon or the winter rains of the north, and the issue of warnings for cyclones raging at sea or bringing flood and destruction on land. These purposes were met by a network of stations reporting ordinary meteorological observations once daily to Simla for a report and forecast covering India generally; and to the three regional centres Calcutta, Bombay and Madras, for issue of regional reports. In times of stress certain additional observations were called for to supplement these routine daily messages.

During the last ten years, however—1924 to the present time—a great revolution in weather requirements has had to be met in India as the flying services have developed eastwards, and the change in practice as seen to-day is little short of magical. The influx on a public service scale of Imperial and international aviation passing through India has called for a system of middle-air exploring stations spread widely over the region from Bahrein and Aden in the far west to Rangoon and Mandalay in the east; and the inland flying services of south India have been similarly protected by exploring stations in the Peninsula. By 1931 the original four centres of daily forecast had been increased to eight, and, in addition, there were 32 pilot balloon stations reporting to them daily or twice daily, and a staff of scientific officers well qualified to make good use of the new material. To-day maps are prepared each morning to show a complete and connected bird's-eye view of the wind sheets over India at seven levels, from ½ km. to 6 km. above ground, and I understand that these maps have very materially improved the accuracy of the daily forecast work of the department.

In the course of this ten years' development, there had first come the R.A.F. service on the Frontier, and Quetta and Peshawar were added in 1925 to the original four regional forecasting centres to deal with their own Frontier areas; and two years later Karachi was equipped as the terminal station of civil aviation from Europe. In 1929 Delhi was added, when civil aviation extended its route through Karachi to the capital city; and finally, when the French and Dutch air mail lines began to pass right through to the east, Rangoon also became a forecast centre.

It is true, unfortunately, that years of leaner budget have followed 1931, calling for a heavy curtailment of programme to meet a sudden cut of some 27 per cent. in expenditure, and that the high hopes and standards contemplated have

FIG. 2.
Air Route to the East.
London to Bahrein, 3,859 Miles. Bahrein to Victoria Point, 3,787 Miles.

had to be deferred, but the department has met the blow bravely, and is using to the full the resources left. For the present the eight forecasting centres have been reduced to five by closing those at Delhi, Rangoon and Madras, and with them five of the less indispensable pilot balloon stations. The service must now, I am afraid, be regarded frankly as a skeleton provision, materially below the standards recommended in the International Air Convention. It is much to be hoped that when the heavy responsibility towards aviation comes to be properly realised, some approach towards a restitution of means to the 1931 standard may be found possible.

That the responsibility borne in India is very great may be seen by considering the range of country for which the Karachi and Calcutta centres alone have to provide flying forecasts and warnings; it extends over the whole 4,000 miles from Bahrein in the Persian Gulf to Victoria Point in Burma, and covers diversities of climate, each with its own dangers. It is thus as widespread as the route from Bahrein westwards to London, which is provided with all the elaborate meteorological service considered necessary by European countries for this western stretch. Over the whole of Europe information becomes regularly available for the drawing of four complete maps each day, and these are supplemented by more frequent reports from stations along the air lines. In northern India the maps are drawn twice daily, and for intermediate times reports of current local weather are passed along the W/T chain of stations. With emergencies they deal separately by additional reports sent direct to aircraft in flight or awaiting a start, as, for instance, when a new danger threatens or an old one has passed off. The inland flying services of southern India, on those parts of their routes which lie between Ahmedabad, Bellary, Madras and Puri, are at present but poorly protected, for they have to depend upon a once-a-day weather map drawn in Poona, and some minor messages from danger points along the course. There is real need to extend the W/T facilities along these internal routes, and to double the present provision of weather charts if standards of safety in any way comparable with those of Europe are to be desired.

The dangers to be guarded against within the Indian flying region embrace most of those known to Europe: storm and thunderstorm, hail and snow, and turbulent winds in mountainous country; and, in addition, sudden dust-storms which may blot out all visibility, rainfall that loses all control of itself, drifting cloud so low that a landing ground may be lost, and now and again a tornado. When hailstorms occur they are frequently on their mettle to surpass those of Europe. Cases are on record where hailstones of five inches or more in diameter have wiped out a whole village, destroying all life, man and animal; and in Simla I have seen ordinary corrugated iron roofing show daylight through cracks in it overhead after the passage of a burst of hail.

In the highlands of Persia and among the mountains of the N.W. Frontier turbulence with strong down-winds and up-winds is a common feature in windy weather, and when the air is dry there is no cloud to give a warning. We have a case in point in the experience of the Everest fliers last year: one of them has written:—

> "We were now very close to the mountain and ran into a prolonged and severe disturbance, as a result of which my accelerometer registered 2.8 g. It was so sudden that for a time I seemed to lose all control of ailerons and rudder, and did not know what was going to happen. The machine rocked, twisted and shook in a way I had never experienced in 18 years of continuous flying."

We have also the circumstantial account of Lord Londonderry's experience on January 21st this year in the neighbourhood of Quetta, when his pilot is reported to have found himself involved in a down-current dropping him something between 2,000 and 3,000 feet in a time interval estimated at only 15 seconds, while a following aeroplane in the same neighbourhood was lifted by an up-current from its

flying height of 9,000 feet up to 14,000 feet. Except when the general weather is windless, mountainous country must always offer these dangers to pilots, and it is now well established that, however steady may be the free wind of the day over the nearby level plains, vortices and eddies in lee of mountain peaks and ridges may be of destructive violence.

I am reminded of an analogous case of turbulent currents induced by the ground contours at Gibraltar. On its eastern face the Rock of Gibraltar rises nearly sheer from the sea for some 1,300 feet, and squarely breasts the prevailing easterly wind of the Mediterranean. In consequence of flying accidents in lee of the Rock a close examination was made some few years ago of the eddy commo-

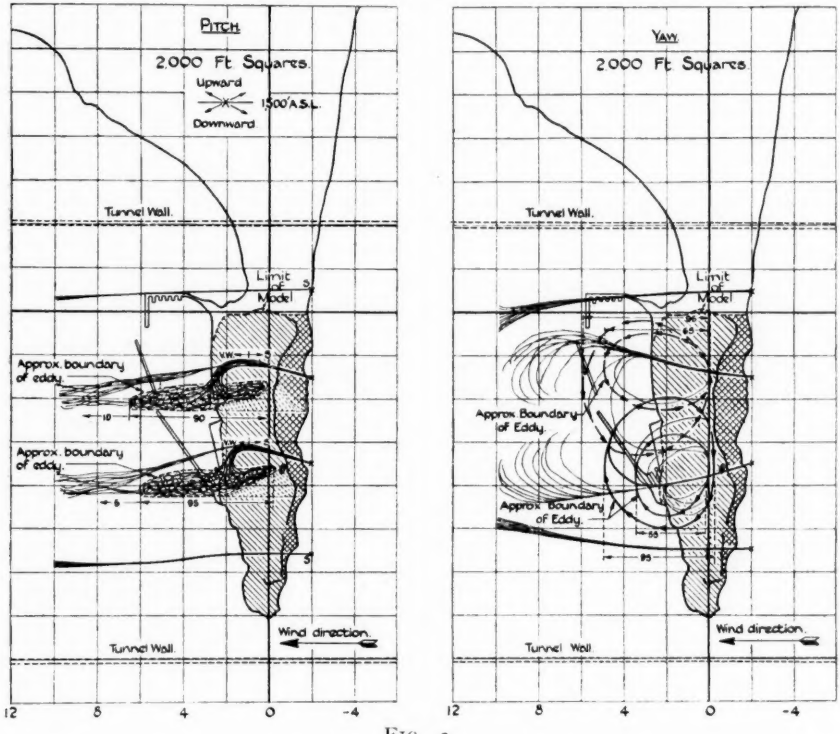


FIG. 3.

Gibraltar Rock. A Model in a Wind-tunnel with Long Fibre Streamers Showing the Vortices in Lee. Wind East.
Height of Origin of Streamers, 1,500 Feet.
Height of Ridge of Rock about 1,300 Feet.

(From *Geophysical Memoirs, No.* 59.)

tion there, and from an official paper descriptive of the results I am able to show a few slides which bring out points of interest. Fig. 3 shows the map of turbulence found by exposing a model of Gibraltar Rock to an east wind in a wind tunnel at the National Physical Laboratory, and this map was verified later to be a true picture in its main features of what occurs on the full-size scale on the ground itself. In the figure, yaw is wind direction in the horizontal plane, and pitch is direction in the vertical. It will be seen that with this wind due east, air currents swarm around the two ends of the Rock and over its ridge, and

that their mutual conflict on the western side produces two vortices, which rotate with alternating mastery of their common ground and sweep from the summit to sea level and well out over the Bay in a generally circular manner. A notable point is that while the central core of each vortex is horizontal when crossing the ridge, it dips steeply on the lee side and buries its nose vertically in the sea, so that at any height up to 2,000 feet strong horizontal whirls are involved, with indescribable confusion in the area between them where they fight for mastery, and alternately gain it.

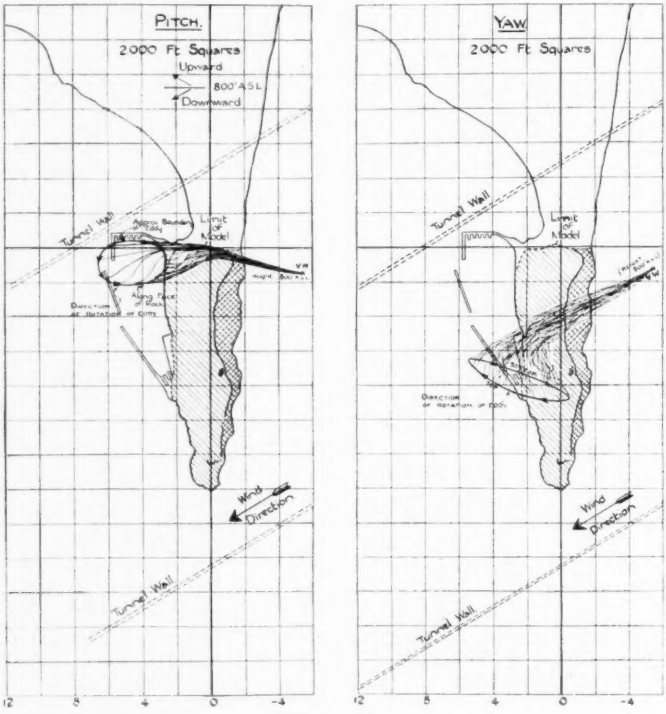


FIG. 4.*

Gibraltar Rock. The Model with Wind N.60E.

But the picture of turbulence behind an obstacle becomes changed with any change of wind direction in relation to the obstacle. In Gibraltar a shift of wind direction from due east to N.75°E. results in the permanent mastery of the northern vortex over its southern fellow, while the greater change to wind N.60°E. eliminates the southern vortex, and turns the vertically-ending core of the remaining one into a horizontal attitude, in which it is found to extend for several miles south-westwards over Gibraltar Bay, with the danger to aircraft of strongly descending winds on its northern face. An observer at Gibraltar, writing in 1914, stated his experience of " an extremely narrow line of conflicting winds of squall force, affecting the water surface of Gibraltar Bay and harbour

* Reproduced by courtesy of the Controller, H.M. Stationery Office, from *The Meteorological Magazine*, No. 817. Feb., 1934, Vol. 69.

over a length of a mile or more," and only a few weeks back (February, 1934) a seaplane, which had alighted with proper caution well clear of the danger area and was taxi-ing on the surface to its moorings, was capsized by winds of this destructive kind. If we may accept these pieces of evidence as generally true of conditions in mountainous country, it appears that a region known to be turbulent will call for measurements of the free wind direction on any given day before a pilot can assure himself of the best route to avoid danger.

It is not, however, only in hilly country that turbulence and vertical currents are to be feared. In the plains on hot days the temperature gradient will often be extreme near the ground, and the state of the air is then unstable. Dust-storms are evidence of this, and dust-devils, of which a dozen at a time may sometimes be visible. On one occasion Agra was training a batch of new observers for distributed pilot balloon work, and advantage was taken of the

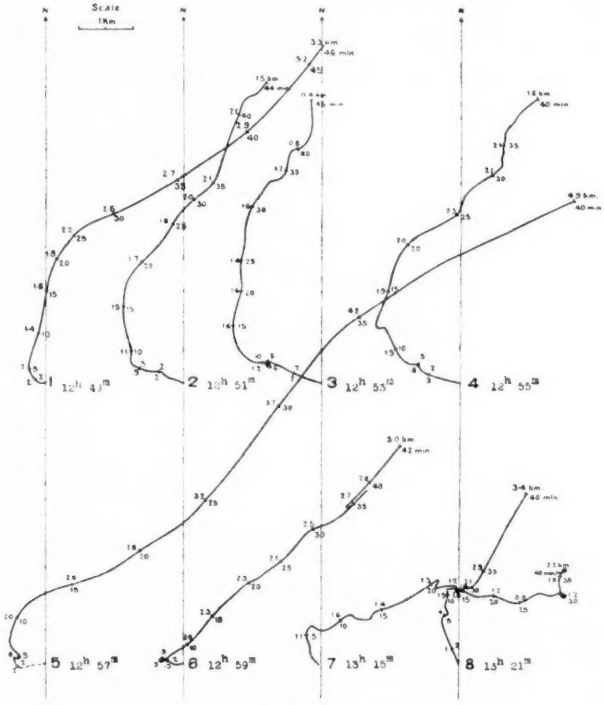


FIG. 5A.
Trajectories of Eight Special Pilot Balloon Ascents at Agra on March 30th, 1928.

large assemblage there of men and instruments to send up at intervals of a few minutes a series of identical balloons. The general weather was somewhat disturbed, and from the behaviour of the balloons shown in Fig. 5B it is clear that strong and rapidly changing vertical currents are liable to sweep the level plains, and these are often the preludes to dust-storms and other dangers to aviation.

Allied with the subject of aeroplane flight is that of motorless soaring, and it is not, I believe, at all widely recognised how far this practice has progressed, and how close a connection it may come to hold with flying in India. About 1910

it was taken up with enthusiasm by a band of young Germans, and a soaring club which resulted has for many years since 1920 held field meetings for practice and research. To-day the conditions are well understood, and so much skill has been attained that motorless sailplanes have soared to 13,000 feet, have travelled 120 miles from point to point, and have remained aloft for very many hours in continuous flight, not merely by day but well into the night.

With success so startling the vogue has spread to Britain, America, Russia and Italy, largely under demonstration by members of the practised club of Germans; and some little time ago the proposal was made to interest India also. When this has been done, I have no doubt that it will appeal strongly to the sporting spirit of Indians, and that with the special suitability of their climate, soaring and long-distance travelling by sailplane will become a serious occupation.

The earlier trials were confined to contoured land where long stretches of continuous up-wind were induced by ground shape alone, but pilots have now learned to poach upon the up-currents of cumulus clouds, and so to become relatively independent. It will be of interest to examine the meteorological conditions of which advantage has to be taken.

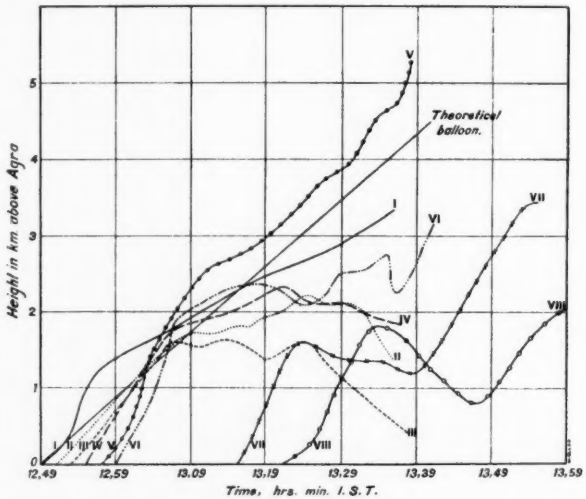


FIG. 5B.

Height-time Curves of Eight Special Pilot Balloon Ascents at Agra on March 30th, 1928. They show up-currents of 450 feet per minute and down-currents of 600 feet per minute.

In the lower air wind strength commonly increases with height above ground, and there results a shearing action which favours turbulence whenever the rate of falling temperature upwards exceeds the known limit of convective stability. It has been shown by Sir Gilbert Walker in the laboratory, and observed in nature out of doors, that this shearing action produces a system of close-packed and self-contained air cells, like a large-scale honeycomb, and that within each cell there is a vertical air circulation with, commonly, a rising air current up the cell axis and the compensating descent along the bounding walls. Such a cell may be of diameter 1,000 to 8,000 feet. When the air is damp enough for cloud formation, as it generally is in Britain, the rising central air of a cell will become capped with a cumulus cloudlet, and on a lightly-clouded day the sky may be dappled with a mosaic of such cloudlets, giving evidence of the honeycomb of cells

and marking out for the soarer the actual positions of the rising air streams which are inviting his use. Sir Gilbert Walker tells me that in his opinion the air cells in India, at times of day when they are strongly developed, are likely to reach to within 50 feet of the ground, so that a sailplane will need only to be started off by a vigorous catapult to be rendered independent and able to keep aloft for the rest of the daylight hours.

It is true that in India during a large part of the year the sky is clear, and gives no cloudlets as visual indicators of the air cells; but the air near the ground is none the less in strong convective motion, so that a slight ridge, a rock, a tree or merely a change of soil surface, will be the base of a rising current, and a pilot will by practice develop a cell sense for these, and will be guided also by the behaviour of birds already soaring within sight. Dr. Hankin, a long time resident of Agra and a close observer of soaring birds, noted that effortless soaring would commonly begin within a few feet of the ground shortly after sunrise, and that the various types of soaring birds chose each its own suitable time to flap up through this distance as a start off for its day's occupation of revelling in the cool air aloft, and watching its human inferior as he laboured in the furnace beneath.

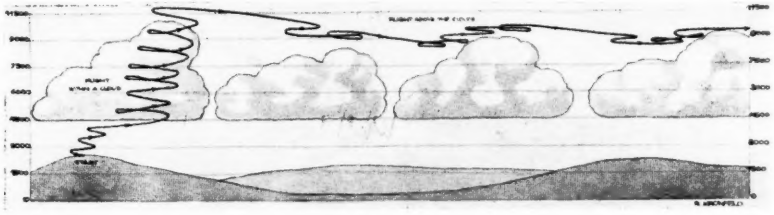


FIG. 6.*
Distance Flight above Clouds.

And now I should like to glance for a moment at the second of the objects to which I have referred as the aims of research in the atmosphere, the mapping of pressure, temperature and humidity from ground level up to 30 km. or more in the upper air itself. The work of exploring this region has become world-wide, and much public interest has in recent years been aroused by the various successful ventures in which observers have risen in person to enter that strange zone, the stratosphere, many miles above the ground.

In early days India started with kites flown on a steel wire, many miles in length, controlled by an engine-driven winding machine, as other countries had done before; and with this equipment vertical heights of about a mile were readily accessible. The recording instrument was housed in the kite, or in some instances was attached to a light travelling carriage left free to run up the wire under its own small sail, with an automatic device by which the carriage, on nearing the kite, threw away its sail and returned with the instrument down the wire to the operator below. Such recorders have been used inland, and on shipboard in the middle of the Bay of Bengal and the Arabian Sea. But nowadays kites on wires, even apart from their limited range of height, are barred as being dangerous to aircraft, and recourse is necessary to balloons carrying the lightest of light instruments, whether the object is to sample the lowest few kilometres only or to penetrate right into the stratosphere.

It was in the closing years of the last century that the researches of Teisserenc de Bort in France first provided evidence that at a height of several

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miles above ground the air temperature suddenly ceased to fall with further ascent, and remained stationary through all the higher ranges reached by his instruments: he had penetrated the base of the region now called the stratosphere. This discovery opened a wide field for conjecture, but I have recollections of my own tacit assumption that similar conditions would be found in India, though the possibility that they would begin at a different level should have been obvious for so different a latitude. I recall also that when we first succeeded in sending up an instrument in the Punjab to the necessary height and reached the base of the stratosphere at several kilometres above its European level, the record brought down showed not a uniform temperature there, but one actually rising slightly with further height; and that, with the European facts in mind, I regarded our own record as in error, believing that this new character was spurious and due to sun-heating of the instrument in the topmost levels. It is now known that the

FIG. 7.*
Launching a Sail-Plane by Catapult.

stratosphere is not limited below by a spherical boundary over the earth; in low latitudes it begins at 17 km. and near the North Pole at 9 km.; and further that its temperature is neither quite uniform everywhere upwards, nor quite steady from day to day over any given place. Fig. 8 shows the average conditions over the northern hemisphere, for the summer in the left-hand diagram and for the winter on the right. This plotting was originally due to Dr. Ramanathan, of the Indian service, and includes the results of many ascents made in India, but the present diagram shows modifications made by Dr. A. Wagner in the light of later information. A glance at the ordinate for latitude 50° shows that the height of the stratosphere base in France and Germany, where the discovery was first made and verified, averages 11 km. in summer, and that a balloon passing upwards will have a further free space rise of some 8 km. with nearly constant temperature; while over the Punjab, or in latitude 27° for Agra Observatory, the

* Reproduced by courtesy of the publishers, Messrs. John Hamilton, Ltd., from *Gliding and Soaring*, by Kronfeld.

summer height of the base is 16 km., and above it a slowly rising temperature will at once be encountered with rise of level.

The recording instruments used in reaching these heights in India were of the type invented and perfected by Mr. W. H. Dines in England; they are mainly of aluminium, weigh a few ounces only, and for years have been made in quantity at the Agra Observatory under the skilled control of Mr. G. Chatterjee, the Director, who has distinguished himself by devising numerous ingenious methods of calibration and use of this and other instruments. Before an instrument is ready for the ascent it has to be proved worthy in the laboratory, and then to be completely calibrated over the range of pressure, temperature and humidity it is to meet in the air; this calibration is a process requiring critical care, and calls for special devices to avoid errors in determining response to the very low pressures and temperatures of the stratosphere.

On the results of many years' work on this and cognate subjects, several substantial Memoirs have appeared, and a new one, of which I have just received

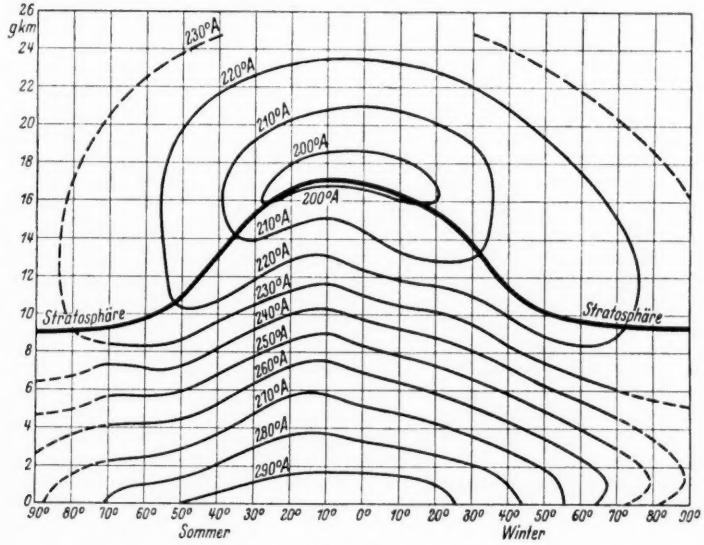

FIG. 8.

Temperatures (absolute) in the Upper Air and Stratosphere, from Equator to North Pole: Summer and Winter Half-years.

the advance proof, deals critically with records of 143 instruments retrieved in a three years' period ending with 1931. With refinement in method the heights attained have increased, and I am informed that while in 1928 only one retrieved instrument reached 25 km., in 1930 there were five, and in 1931 seven, which reached or exceeded that level. The ascents have been made over the wide range of country from Agra to Poona and Madras, with a view to increase our knowledge of the general framework of the circulation, and it is intended now to organise simultaneous ascents of these recording instruments at four distributed places within the areas affected by monsoon depressions. When it is remembered that of the instruments sent up many are necessarily lost in jungle or sea, it will be realised that the work done in this branch of research has been very extensive and creditable, and it is only one branch among several of importance which the department has actively in hand, but which time does not allow me to touch. In

conclusion, I would wish to express my lively regard for the keen and capable staff of Indian officers whom Dr. Normand has had the good fortune to secure as his co-workers in India.

Discussion

The Chairman (Dr. G. C. Simpson, Director, Meteorological Office): There was one point which he wished to stress: Mr. Field had given one the impression in his paper that the upper air work done in India was mainly connected with aviation. Now that would be an entirely wrong impression to take away. The facts were quite different. Aviation was an unlooked-for product of work which had been done for scientific purposes. Mr. Field's first experiments were made with kites at Karachi, and after that he investigated the conditions of the monsoon. It was then that the Chairman first came into touch with this work, and they both went to Belgaum, south of Bombay, in order to get the full blast of the monsoon. They were not very successful. Their kites were frequently broken by the strength of the monsoon, and they struck a patch of unsuitable weather. Afterwards Mr. Field found kite work was not satisfactory because the kites could not get very high, and so he turned to balloons for getting temperatures of the upper atmosphere. He went to do that work at a place called Jhang, in the Punjab, which he believed was the hottest place in India, and Mr. Field chose the hottest season to go there. It was really remarkable the work which was done under those conditions. The lecturer started the investigation of the upper air in India purely and simply as scientific research. That was in the years 1906 to 1908, when aviation had not even begun. Mr. Field so impressed upon the Government the importance of his work that three lakhs of rupees were given for air research. In 1912 Mr. Field gave up all administration work and went to Agra where he founded an observatory for upper air work which was the best equipped in the world, with the possible exception of Lindenberg in Germany. He was joined there by Dr. Harwood, and the last work Harwood did in India was to work up the results which had been obtained in Agra under Mr. Field. When the Chairman left India in 1920, Mr. Field had to give up his work at Agra and return to Simla. Mr. Chatterjee very successfully took over the upper air work.

Continuing, the Chairman said that he would like to broach a subject not touched on by Mr. Field. Those of the audience who were familiar with meteorology in India would know that the outstanding work there had been an attempt at seasonal forecasting of the monsoon. Mr. Field had not mentioned that, because only a few years ago Sir Gilbert Walker had spoken to them in that hall on the subject, but he wished to say one or two words because at the present time seasonal forecasting was a matter of importance in England. England was just going through a most anxious time as the result of a great drought, and the question arose whether in the future it would be possible to forecast drought conditions of that nature. No one had any idea at the moment why these series of droughts occurred. No meteorologists could tell why a series of months were dry and another series were wet. A similar problem, of course, was the seasonal forecasting which was being done in India, and any solution of the English problem would, without doubt, depend on the work which had been done in India.

There was one aspect of the work in India which he felt he was in a better position to speak about than Mr. Field. When the Indian Meteorological Department was reorganised in 1904-6 there was, he believed, only one University-trained Indian in the whole of the Department, namely, Dr. Moos, at Colaba Observatory, Bombay; but there was in the office at Simla a delightful Indian gentleman, Lalla Hem Raj, who, although not trained as a physicist, had a better grasp of Indian weather than anybody he had ever met. Those were the only two Indians of officer rank in the Meteorological Department at that time. Looking at the Department to-day, one found an entirely different state of affairs, for now there were only two Europeans in the Department and the officers were

a body of young University-trained Indians, several trained in England, who were doing splendid work for meteorology. The series of papers which they were turning out, published in their own Meteorological Memoirs or their own Professional Notes, would be a credit to any body of meteorologists.

Sir ATUL C. CHATTERJEE, G.C.I.E., K.C.S.I.: He had the good fortune of being associated with Mr. Field at one time of his life, and he knew they were very fortunate in having that lecture from him. He was quite incompetent to speak in regard to the scientific part of the lecture, but he had listened with great interest to what Mr. Field said in regard to the development of that work in India, and also to the remarks which had been made by the Chairman, one of the greatest authorities on the subject. He was glad to see present another leader in that work, Sir Gilbert Walker. They owed to men like Simpson, Field and Walker the very great debt of training Indians to carry on that work. Dr. Simpson had mentioned the fact that now the Department consisted practically entirely of Indians, although they still had the guidance of one or two experienced and extremely able Englishmen. It was difficult, in these days, to secure for scientific work in India the best Englishmen and to retain them there, and therefore it was a very great advantage that they had now a body of Indians who could carry on the good work that was initiated by British pioneers.

He noted with great regret what Mr. Field said about the cutting down of the work in that Department. The work in the various scientific departments in India had undoubtedly suffered as a result of retrenchment. The Government of India had been hard put to it to balance the budget, and he personally regretted very much that they found it necessary to cut down the scientific departments. He hoped that for the sake of development in India, which only would bring back prosperity to that country, the Government would find it possible to restore such cuts at the earliest possible moment.

Sir GILBERT T. WALKER, C.S.I., D.Sc., F.R.S. (Professor of Meteorology, Imperial College of Science and Technology): It gave him very great pleasure to associate himself with the lecturer and Chairman that evening in view of the many years of happy work which they had carried out together. Formerly his greatest difficulty in connection with Mr. Field was to get him back from the arduous duties which he undertook of going into the desert at the hottest times of the year or sending up kites from small boats in the Bay of Bengal, and he used to be really anxious about his survival. He noticed that Mr. Field had come back somewhat mellowed by experience; by contrast with his former attitude regarding budget reductions his present remarks seemed almost unlicensed in their moderation. They all realised that the Government meant well, and that when the amounts available were cut down and observers had to be dismissed, the only course was to shrug their shoulders and hope for the best. He thought that, to a certain extent, the meteorologists were responsible for their misfortunes, because they habitually spoke of research work when they were describing merely the acquisition of information for future use. If they wanted to know what the winds were nowadays solely for the purposes of aviation, it might be described as research work, because it brought new information; but the term was misleading if it led those who were controlling them to imagine that they were making investigations into the unknown merely with a pious hope that the results might be of value in the future.

With relation to what Mr. Field said about gliding, he (the speaker) was particularly interested personally because he did what he could to get experiments started in regard to the possibilities of India. He honestly thought that over a large part of India one could start up in the morning, remain in the air until the evening, and cover a considerable distance, probably with a good deal of control in regard to the direction. In relation to the height of 13,000 feet to which Mr. Field alluded, if they got to that height in Brazil they could certainly do it in India. If the angle of descent was 1/20, the glider would cover something like

50 miles before reaching the ground, without further help from up-currents; they were certainly looking forward very much, as meteorologists, to the information that gliding would give them. In the diagrams they saw that much use was made of cumulus clouds. The ordinary person thought that the top of the cloud marked the top of the ascending current, but gliding showed, under certain conditions at any rate, that they had a much greater extension of that upward movement than was generally recognised at present.

He would like to emphasise what the Chairman said with regard to the work being done by Indians in the Department. They had shown themselves the most loyal colleagues, and in particular he would recall Rai Bahadur Hem Raj, who, during the war, was working at Simla under great difficulties; the gazetted officers had been largely sent away, and when Hem Raj was breaking down from overwork he would not declare himself unfit, with the result that on Sir Gilbert's return from leave he found him on his deathbed, simply because he refused to call in help when most men certainly would have done so. He had shown an example of loyalty which those who knew him would not easily forget.

He would like to ask Mr. Field whether he had any information in regard to the great heights which were said to have been attained in India by sounding balloons, heights of 30 kilometres or more; further, whether the upper air traces of balloons showed much evidence of up-and-down movement, as one would expect to find on account of the great vertical currents requisite for the enormous hailstones to which Mr. Field had referred.

Lieut.-Colonel E. GOLD, D.S.O., O.B.E., F.R.S. (Assistant Director, Meteorological Office): He supposed that many people had the idea in earlier days that India was a country in which one put up a forecast some time in the autumn or winter to the effect that the next two or three months would be fine, and that later on in the year, towards the beginning of June, another forecast was put up saying that in the next three months there would be 3,000 millimetres of rain—plus or minus 2,000. It was clear now that in India they had uncontrolled rain, and that day-to-day conditions required forecasting there just as they did in this country. That was particularly important in connection with the development of aviation. Dr. Simpson had emphasised the fact that early researches in India were initiated for pure research, because there were things which they did not know, and it must be realised that India was in a peculiar position from the point of view of world meteorology. One of Mr. Field's maps had shown a great black patch, representing the biggest plateau in the world. Nobody could think that that large black mass produced no effect upon the atmosphere, or that the currents and changes went on just as if it were not there. That mass of Tibet might be one of the most important factors in deciding the course of world meteorology. India was in the best position, because it was the most civilised country in the neighbourhood of that patch, to investigate the effects of the Tibetan Plateau and to tell the world of the circulation of the atmosphere. The observations from India had already given them new information, and a continuation and extension would give them more chance of getting the full value out of it. That was to some extent a digression which he had made, partly because he wanted to emphasise what Dr. Simpson said about the initiation of the observations in India and the need for getting more knowledge without necessarily knowing exactly what practical application they intended to make of it. If they sought more knowledge about upper air and the currents over India than they had already got, they would benefit, because they had that knowledge. They could not see, as Mr. Field mentioned, when they got knowledge of that kind what the practical applications might ultimately be.

Referring back to the question of meteorology and aviation. There were two things that struck one. There was 4,000 miles for which a single air service was responsible. That 4,000 miles comprised a great variety of weather, and there were just the same kinds of dangers and difficulties for aviation there as there

were here. At present international aviation across India might run only once or twice a week, but it was not going to be confined to that, and a meteorological organisation for aviation could not be built up at a moment's notice, or even in a year or two, if they were going to meet the needs which India must have for aviation in the future. The curve of meteorology for aviation was bound to go upwards in the long run. They knew from experience that progress was often made, not because men who looked ahead could get their way, but because an accident occurred. He was sure India did not want that: her meteorology in regard to aviation should not become spasmodic—going down because of starvation and up because of accidents—but should progress steadily. He would like to emphasise what Mr. Field had just lightly touched upon, the need for the development of meteorological services in India to meet the future development of aviation.

Mr. W. A. HARWOOD, D.Sc.: The first question he would like to ask was in connection with frontal forecasting, *i.e.*, the distinguishing between masses of air of different properties in connection with day-to-day forecasting. Anyone who had had practical experience of frontal forecasting knew the difficulty of making the analysis, and must admire the keenness with which the Indian meteorologists had set about the work. The Norwegians for their analyses demanded a network of stations so close that the stations were only about 80 miles apart, and observations separated by intervals of not more than six hours. When one thought of that in connection with the distances between stations in India, and with the two observations taken a day, which Mr. Field mentioned, one could realise how very great the difficulties must be in doing the day-to-day analysis there. In making the analyses one had to use scientific imagination a good deal, because one never got, for instance, the upper air observations which one needed in order to put in the boundaries of air masses directly from the observations; but, of course, one could make an analysis depending on imagination alone, and it would be interesting to know how much imagination was involved in the analyses which had been published (not only as regards horizontal distribution in India, but also as regards vertical distribution), and how far the results of the analyses had checked off against actual weather.

The question he would like to ask was: how useful the analyses in India had been found in connection with day-to-day forecasting?

The second question was more of an administrative nature. He had been asked recently on several occasions by officers of ships sailing in Indian waters how it was that there was no synoptic message available which would enable them to plot for themselves weather maps over the sea so as to be able to judge for themselves, at any rate roughly, what the prospects were in those sea areas. One could realise that there might be difficulty in organising such things in India, for example, in connection with wireless communications, but it would be very interesting if Mr. Field could tell them definitely why it was not possible to furnish those synoptic messages. It would enable him personally to give a satisfactory answer to questions that he was asked from time to time.

Colonel M. N. MACLEOD, D.S.O., M.C. (War Office): There was one matter to which, in case they did not know it already, he would like to draw the attention of meteorologists. It was connected with aerial photographic methods of surveying. This was a new technique which had aroused a good deal of interest, and one of the questions to which an answer had to be found was what were its economic and commercial possibilities? The principal factor in that was the cost of flying the aeroplane, and if an aeroplane was to be flown up to say 10,000 or 15,000 feet, it was absolutely essential that it should have a cloudless day. To spend money on getting an aeroplane up to that height and then to find that the view was obscured meant a serious waste of money. It was impossible to estimate the commercial or military possibilities unless one could get some sort of idea as to the number of cloudless days throughout the year, how they were

grouped, and if they were grouped in any systematic way so that they could be forecasted. In this country such experience as he had was that the number of suitable days was extremely few. On some occasions they had had to wait for six months, or even a year, for a suitable day, *i.e.*, one that would remain clear long enough for an aeroplane to get off the ground and remain in the air photographing for two or three hours. He hoped that meteorologists would be able to supply this information to surveyors.

Reply to Discussion

The Lecturer: He wished first to thank Sir Atul Chatterjee for his kind remarks. Sir Atul had been his Honourable Member of Council, and the lecturer remembered well how pleasantly he had refused his application for funds on a particular occasion. It was at a time of considerable financial stress, and other departments besides his own were asking for favourable consideration, so that the Honourable Member's adverse decision did not indicate any lack of sympathy with the department, or of appreciation of its object at the time.

Sir Gilbert Walker had drawn attention to the misuse by scientific departments of the word "research," and suggested that such misuse might partly account for the failure to secure grants for essential work, ahead of the time when administrative control would itself recognise the need. This was a point of real cogency, and it would probably be a good move to banish the word "research" from the meteorological dictionary and to substitute some such expression as "overdue investigation." It had certainly been a common experience that a timely spending of money on scientific inquiry had saved many times its cost by avoiding the excessive expenditure for the same result, which deferment, and consequent hurry, so often involved. A conservative attitude was, of course, as necessary in asking for funds as it ought to be in a refusal of them by Government, but in the lecturer's experience in India mistakes by the meteorological department in foreseeing real needs, or in over-estimating their urgency, very seldom occurred.

Sir Gilbert Walker had asked what recent success had followed attempts in India to reach great heights in the stratosphere with recording instruments on balloons. A few details had already been mentioned in regard to the increasing frequency of reaching 25 km., but it might be added that some very high flights had been recorded; several had closely approached the 30 km. level and two were understood to indicate heights considerably greater, but in the lecturer's opinion these two records would need very critical examination before their upper portions could be regarded as acceptable. On Sir Gilbert's second question, very vigorous currents were quite commonly shown by pilot balloons in the hilly regions of the Frontier, and on occasions in the plains generally. In Quetta the records had shown up-gusts certainly as strong as 1,000 feet per minute, and corresponding down-gusts, but of less violence. In Jubbulpore, Delhi and Trivandrum such currents had appeared to measure even 1,500 to 2,000 feet per minute upward, and there was no reason to doubt that vertical winds of these magnitudes occurred in weather associated with hailstorms. Two cases of much interest might be mentioned: they were found not by mere pilot balloons watched by theodolites, but by the larger balloons which carried actual recording instruments, and these had been repeatedly swept up and down, perhaps by miles vertically, in the grip of violent blasts. Hailstones were known to be swept up and down alternately for great vertical distances, and as many, perhaps, as twenty times in succession; and each trip added a fresh coating of clear or cloudy ice to its size. But as the type of instrument used in India had pressure and temperature for its co-ordinates and did not mark on a time-scale (it was a question of cost, merely, which decided against more elaborate instruments with a clock-driven time-scale), repeated rises and falls had to retrace the same figure in the record except where the succeeding conditions of temperature varied over a given height range between

one up-rush and a later one. It was not possible, therefore, to say how extensive the up and down rushes had been nor how often repeated, but the records indicated at least twice, and it might well have been many more times.

Colonel Gold had been struck with the meteorological importance of the high plateau of Tibet and central Asia, lying between 12,000 and 18,000 feet above sea, on the slide that had been shown. In earlier years it had been considered that across that northern boundary of India the monsoon could never pass, and although the upper winds now certainly showed that this could not be entirely accepted, the fact remained that the barrier limited and profoundly modified the air currents on which the rainfall of India depended. Of lesser mountain ranges there was the long stretch from Bushire eastwards to Quetta, a tract where routine aviation now had its dangers from turbulent currents; but perhaps a greater danger still lay in the wind-blown sand which sometimes obscured visibility there, as he believed was the case when some few years ago Sir Samuel Hoare flew east to India and had to turn back when nearing Karachi, to await better conditions.

Colonel Gold had fully realised the need of a liberal treatment of present problems, and certainly the cut of 27 per cent. in funds, to which reference had been made, was a serious matter. One could well understand that it was not feasible for a Government to provide against discontinuities of policy in times of budget difficulty, as a railway company could do, or a big commercial organisation, by falling back upon an accumulated reserve fund; and so a scientific department must suffer correspondingly when resources dried up, for a sudden cut of 27 per cent. meant probably a 50 per cent. loss of value for the period immediately following. It was not easy to realise fully the extent of the disorganisation that must occur of men, instruments and methods.

Dr. Harwood was an expert in air-mass analysis, and had asked how India stood in this regard. It was believed that such analysis was done from day to day in India as far as resources allowed, and the daily charts of upper-wind sheets in seven levels up to 6 km. had been found of great use in this work. With the further help of the close detail in surface observations which had been organised in recent years, the meteorological department was able to distinguish between "frontal" and other types of rainfall. It was naturally the case that daily analysis could not be complete, for details of upward gradients of air temperature did not become immediately available, but special cases of analysis in typical instances of weather could be dealt with and examined at leisure, though even then some 40 per cent. to 70 per cent. of the instruments sent up were necessarily lost in jungle or sea.

Turning to Dr. Harwood's second question on synoptic broadcasts from which ships could plot their own contemporaneous charts of weather conditions, he was uncertain how far India had become ready to follow the practice prevalent in the Mediterranean, the Atlantic, and elsewhere. The demand for synoptic broadcasts had long ago been expressed and met in these European seas, and much use was made of the information by naval and mercantile ships; but in the lecturer's experience no demand had arisen up to some years ago in Indian waters, ships having been content to receive the digested conclusions issued broadcast by the meteorological department when occasion had arisen for them. Doubtless modern interests would call for this advantage in the East, if they had not already done so, and in that case it would be important for the code used to be the full international code employed elsewhere.

Colonel Macleod has been troubled with interference through cloudy weather in aerial survey work. In India, where cloud is much more amenable to expectation than in this country, pilot balloon stations made notes of cloud details such as amount at all hours of day and night, development, type and the proportions of type present at any time; and by now it would probably be true to say that at most times of the year the Weather Headquarters at Poona would be able to

answer correctly any questions of the probability of clear or cloudy skies a day or two in advance. The Everest Expedition had had, he believed, some difficulty in regard to their survey photographs, but they had made use of infra-red exposures and had found that this helped them, at any rate against the obstruction of haze. How far infra-red photography would help in case of thin cloud he could not say, and in regard to the general conditions of cloudiness in England he could only refer Colonel Macleod to the English authorities.

On the motion of the CHAIRMAN a very hearty vote of thanks was accorded to the lecturer, and the meeting terminated.

THE DEVELOPMENT OF AVIATION LIGHTING*

BY

MAJOR R. H. S. MEALING

Prior to 1914 there was no night flying proper, as we know it to-day, and therefore, so far as I am aware, there was no night lighting. I must except, of course, the night flying exhibitions which were given at Hendon in this country and at a few places abroad.

To enable those exhibitions to be given the aircraft was outlined with small electric lamps, and the illumination to enable it to land was afforded by burning petrol in a bucket.

Then the Great War came, and with it the necessity for night flying proper.

Various devices were used for assisting aircraft to land, but the principle was always the same—namely, a line of flares—petrol or electric, in such formation as enabled a pilot to know—

(*a*) The position of the landing area proper, and
(*b*) To enable him to judge his height above the ground.

The most important development was the introduction of the aerial lighthouse. These were used in France to enable night flying squadrons to find their way home after bombing raids. They were, of course, an excellent aid to the night flyers, but they were also an aid to our then enemy aircraft for the reason that, as I know to my cost, when commanding a day scout squadron which was using the same aerodrome as a night squadron, we were flying most of the day and being bombed most of the night.

As in so many cases, good came from evil, and to-day civil routes throughout the world are provided with airway beacons which have gone far to make night flying safe.

I give just this very cursory picture of night lighting prior to and during the war, and now we arrive at the birth of civil aviation as we know it to-day.

Civil aviation in this country began its life at Hounslow Aerodrome (now returned to its former use as a cavalry training ground). There was erected the first aerodrome beacon, which was first operated on December 29th, 1929. This light was supplied by the Gas Accumulator Company, Ltd., who thereby had an early if not the earliest connection with night lighting in this country, and I would like to take this opportunity of thanking Mr. A. G. Watson, of that firm, for the very valuable notes which he has supplied to me for this paper.

Prior to this date all beacons had been of the searchlight type, and one can readily appreciate the fact that a pilot is either in or out of the beam—mostly the latter—and from that date it was known in this country that the searchlight type of beacon was no use.

In spite of that it is worth noting that other countries for years afterwards continued to use the searchlight beacon until they realised that the very time it was wanted (*i.e.*, at close ranges in bad weather) it could not be seen.

I suppose we were, as ever, better at scientific design than publicity, and it is certainly due to that error that the very false dictum (namely, " Airway beacons

* Abstract of a lecture read before The Illuminating Engineering Society, Nov. 14th, 1933.

are no good, because when you can see them you don't want them, and when you want them you can't see them ") arose.

Those of us who are trying to forge ahead with night lighting are still having that fallacy thrown up at us.

I would like to take this opportunity of most emphatically saying that whereas airway lighting by itself is by no means valueless; as an aid to air navigation it is invaluable.

And that is the way airway lighting must always be considered—as an aid to air navigation.

In April, 1920, Hounslow was given up as the civil aerodrome for continental traffic, and Croydon took its place, but not of course the Croydon airport as we know it to-day.

New beacons, obstruction and boundary lights, an illuminated wind indicator, and even a landing floodlight, were within a very short time provided there.

Airway beacons were also provided on the Croydon continental route, and although very material changes have since been made to the actual apparatus, I think that acknowledgment should be made of the credit due to those who first devised the principles of this system of lighting, because, with certain slight alterations it holds good to-day throughout the world.

From 1922 progress was slight, and, although as I have said credit should be given to those in this country who devised the present-day principles of night lighting, it certainly required the enormous growth of night flying in America from 1928 onwards to provide the impetus which has to-day enabled us to make night landings at aerodromes and navigation on airways as safe as it is; and what is above all so very necessary to provide the stage at which international agreement has arrived.

This question of international agreement is an extremely important one when you realise that the night-mail machine of the future will pass right through some countries in two to three hours.

We must ensure that we in no way hinder development of the apparatus used, but even to-day we know enough to standardise principles, and it is by that standardisation that we can simplify night lighting, and directly by its simplification can we make night flying safer.

The first step in obtaining this international agreement was taken by the International Illumination Commission at its meeting at Saranac (U.S.A.) in 1928.

Other than the fact that up to that time there had been a small amount of international agreement on the subject of lighting by virtue of the agreement contained in the International Air Navigation Convention, I will not go so far as to say that that agreement was honoured more in the breach than in the observance, but it certainly has not been strictly adhered to.

Be that as it may, the agreement that was reached some twelve or so years ago formed a very useful foundation for international agreement, and it is only within the last year or two that we have been able to formulate any suggestions for amending it.

The manner in which the question of obtaining further international agreement was approached to decide the minimum amount of lighting required, to define and state the fundamental requirements of each necessary light, and perhaps later to prepare a specification for the lighting as a whole.

I can perhaps indicate the suggestions for international agreement and the work of the British Aviation Lighting Committee at the same time.

It is necessary to divide aviation lighting into two subjects, viz.:—

(*a*) Airway lighting.
(*b*) Aerodrome lighting.

I will deal with these two subjects in the order in which I have given them, because it is in that way easier to indicate how an aeroplane is guided along its route to its destination and then assisted to land.

Airway lighting can of itself be divided into two parts, which might be referred to as the aids and hindrances to air navigation. By " aids " I mean the beacons which show the way, and by " hindrances " the obstructions which get in their way.

The two most important requirements for an airway beacon are its design and its location.

For use in a country which is liable to suffer from bad visibility, and yet which is not too bad for flying, it will be readily appreciated that it is most important that the design of the beacon must be such that its angle of light-distribution in a vertical plane should be continuous from the horizontal to the zenith. The horizontal part of the beam of great intensity enables the beacon to be seen in good visibility at a great range and the vertical part of the beam which, although its intensity is not and cannot be so intense as the horizontal beam, enables the beacon to be picked up in conditions of bad visibility at short ranges if not when actually over it.

I can illustrate the necessity of having plenty of light in the upper limits by saying that in clear weather I have been not more than 1,000 ft. above Dungeness marine lighthouse, and although I knew I was directly above it, I was quite unable to see any light. It will be understood that if such a light, which it must be accepted for the purpose of aviation lighting is a searchlight, is useless in clear weather, it will equally be understood how utterly useless it is in bad weather.

It will be within your knowledge that from the year 1928 a very large amount of money was expended in America on the lighting of their airways, and the beacon which was used for that purpose was one of the searchlight type with the beam directed slightly above the horizontal.

It was soon discovered that whereas such a beacon was excellent when viewed at long ranges and in clear weather at short ranges it was practically invisible, and I understand that many, if not all, of their airway beacons have been modified so as to show a secondary beam at 55° above the horizontal.

Without desiring to be egotistical about the latest British type of airway beacon merely because it is British, I feel sure, for the reason that its light distribution is continuous from the horizontal to the zenith, that the design is correct. I must, however, emphasise the fact that the design is applicable mostly to this country where a large percentage of bad visibility prevails.

For overseas use, and particularly for Empire routes, one can almost entirely rely on long-range beacons where the light distribution is concentrated to a high intensity in a small vertical angle just above the horizontal. The reason for that design is that visibility overseas, whilst not quite without exception, is mostly so good that it is not necessary to deflect any of the light into the upper angles in order to use it as a short-range bad weather beacon; and when the visibility is bad it is so bad that it is practically impossible to fly and the beacon is not required.

The location of the beacon has to be considered in two planes—horizontal and vertical. It must as nearly as possible be on the exact line of the airway, and it must also be above the fog line and below the cloud line. In this country that usually means a height above sea level of anything between 200ft. and 500ft.

Many attempts have been made to recommend a definite and fixed distance between one beacon and the next along an airway, but I am firmly of the conviction that not only is that the wrong method of spacing beacons but, having regard to the manner in which the topography of a country can vary in a short distance one can say that such a method is impossible.

One can, however, define a principle for spacing beacons which will suit all types of beacons and all kinds of topography. It is this: Beacons should be

spaced in such a manner that, having regard to the local topography, a pilot who does not deviate more than 5° from the track between any two beacons will pass within visible range of the next beacon under the worst weather conditions in which regular night flying would normally be carried out in the locality. By following that principle one can employ small beacons closely spaced, such as might be necessary in hilly country, or one can use large beacons widely spaced in open country.

I have not referred to the character of an airway beacon.

It has been in the past our habit to use Morse characters, but there is more than one objection. In the first place, there are few Morse characters which can be used owing to the difficulty of having the character repeated in a reasonable time. Secondly, one cannot obtain a high enough intensity with a Morse character beacon; and, thirdly, from a navigational aspect, it is difficult, if not impossible, for a pilot to memorise a large number of characters which would be necessary owing to his passing a beacon somewhere about every ten to fifteen minutes. Therefore it has been decided to use what is known as a single-flash beacon. This type overcomes every one of the objections to the Morse character beacon.

To enable a pilot to know not only which route he is on, but precisely where he is on that route, each beacon will have a small short-range identification light on the top, which will have its own character, and will not be repeated within one hundred miles.

The colour of the main beacon will be white, and that of the identification light red.

A pilot will thus be led along his route by a chain of beacons whose main character will be a single white flash, visible at long range in good weather, but equally visible at short range in bad weather, and will, in addition, be able to identify each beacon (which will be marked on his map) as he travels along.

In that manner will he be " aided." One must now consider the manner in which he will or might be " hindered " by obstructions.

So far as the physical features of the country over which a pilot is flying are concerned, he can normally acquire all the information he requires from his map. But there may be some artificial obstructions on or near enough to his route as to be a danger. By artificial obstructions I refer to wireless masts, very tall chimneys, overhead electric cable towers, and anything else which comes under the same category.

Where such an obstruction constitutes a danger to air navigation it should be illuminated by night with fixed red lights, of which one will be at the top and the number and location of the others according to the height of the obstruction above the ground level.

To illustrate how many factors have to be taken into consideration when dealing with lighting, not very long ago some wireless masts were erected not far from the Manchester municipal airport, which masts are used in conjunction with the wireless station at that airport. These masts were also quite near the Manchester-Liverpool railway line. The Air Ministry specified the number and type of obstruction lights which had to be fitted to each mast, and they were duly fitted.

It was not very long before we had frantic messages from the London Midland and Scottish Railway Company saying we were stopping all the trains from Liverpool to Manchester. Little did one know that the red obstruction lights on the wireless masts were dead in line with one of the railway signal posts where the railway line makes a slight curve.

That was bad enough, but what the L.M.S. authorities were quite naturally really frightened of was that, sooner or later, a driver might think he was looking at the wireless mast, whereas he was looking at the signal light, and go past it with disastrous results.

That difficulty was got over by fixing very small shields in front of the obstruction lights on the masts. Those shields have proved sufficient to prevent the light being seen from the railway line, and yet hardly detract at all from the usefulness of the lights for the purpose for which they were provided.

I should like to make a brief reference to the danger caused by the new overhead electric cable system, commonly known as the " grid " in this country.

They must first be considered in the light of whether they are or are not an obstruction. Most often, except in the vicinity of an aerodrome, they are no more dangerous than anything else. If, however, by virtue of their height and/or their location, they do constitute an obstruction, they are undoubtedly an exceedingly dangerous one.

We can now imagine that a pilot has been led along his airway by the beacons; he has avoided the dangerous obstructions because they are illuminated, and now he is approaching his aerodrome of destination.

It has been written that the aerodrome of the future will be built first, and that the city will be built around it. I am not going to say that, but it will certainly be necessary for some aerodromes to be located well within the confines of the city—there are some examples already.

But for the time being most aerodromes are located on the outskirts of the city.

A pilot has got to be told exactly where the aerodrome is, and although he will be led practically to it by wireless, he requires to have it indicated to him more precisely by an aerodrome beacon. When one considers the thousands of multi-coloured, sometimes flashing, advertisement signs which have been erected in the last few years, one can realise the difficulty of designing a beacon which can under no circumstances be mistaken for one of those signs or for any other light.

That beacon has to be distinctive from every light in the district, and has moreover got to be different from any other aerodrome beacon in the same district.

That beacon should be placed on or near to the aerodrome it is to indicate.

It is suggested that normally an aerodrome beacon should be red in colour and possess a code character which will consist of a single Morse letter. The same code character should not be allotted to any two aerodrome beacons within 100 miles of each other.

It is common knowledge that for some time many people were under the impression that the light emitted from a neon tube possessed some inherent property which enabled it to penetrate fog better than any other light. I am assured by those better qualified to speak than I am that such a supposition is incorrect.

Whereas the neon tube lends itself admirably for use as an aerodrome beacon, it possesses no better fog-penetrating power than a white light passed through a red filter emitting the same hue wave-length.

It might be asked is it not necessary for airway beacons to be as distinctive in their character, particularly with regard to colour, as the aerodrome beacon?

The answer is no. From the very nature of the requirements of each, the aerodrome beacon must emit a low-intensity light, and the airway beacon a high-intensity light, and one cannot, I understand, obtain a high-intensity coloured light.

The pilot has now been led to his aerodrome of destination by the aerodrome beacon, which can be very easily distinguished from all other lights in the district. He now requires to know the precise size and shape of the landing area, and this information he obtains from what is known as the boundary lights.

The function of these lights is to outline by night just as clearly as a fence, hedge, or artificial markings will do by day, the actual perimeter of the landing area within which it is safe to land and operate.

The International Convention requires that boundary lights should be red in colour, but the various meetings of the International Illumination Commission

have gone to show that there is from the technical aspect international agreement that normally they should be orange in colour and fixed in character.

It is also suggested, as the result of certain experiments which have been carried out, that they should be spaced at intervals of 300ft. on the perimeter of the landing area. This figure was found to meet the requirements of a pilot being able at a glance to draw an imaginary line around the landing area, and yet was economically possible.

Any larger spacing did not meet the requirement mentioned, and any smaller spacing was unnecessarily expensive.

The pilot has now been led to his aerodrome, knows its size and shape, and prepares to land.

His first requirement is to ascertain the direction of the wind, for it must be remembered that an aeroplane must always land against the wind.

He obtains the direction and possibly the velocity of the wind by reference to an illuminated wind indicator.

This piece of apparatus takes the form of the letter " T," both arms of which should be approximately equal in length, and not less than 16ft. in length.

The apparatus is so fitted with vanes along the main arm that it lies with the head at 90° to and against the wind. In other words, the direction of landing is as shown by the main arm in the direction of the head.

The " T," as it is called, should be outlined by white light, or any colour approximating thereto, to an intensity of 10 to 15 candles per foot run.

The pilot can now choose his exact line of approach for landing and begins to glide down.

Try as one will, one cannot avoid having many dangerous obstructions around and on an aerodrome. It is necessary to light every one, and that is done by outlining them vertically and horizontally by fixed red lights.

Such a form of lighting will enable the pilot to glide either over or past them.

All that is now left for the pilot to do is to land the machine, and for that purpose he requires a landing area floodlight.

He should normally land over the floodlight, and then down its beam.

Many devices have been produced to enable the pilot to land across or even against the beam, but I think it will be agreed that the ideal form is where the pilot lands over the light and away from it.

Thus the pilot ends his journey. By the aid of various forms of lighting he has been led along his route, and he has avoided any obstructions thereon. He has been brought to his aerodrome, and then safely led down to the ground.

I have not supplied any technical data regarding the actual lights because that will, in due course, be issued in the form of a British Standard Specification, which specification one can express the reasonable hope, in view of the measure of agreement which has already been attained, might become international at least in principle if not in actuality.

What I have actually done is to more or less describe the work of the British Aviation Lighting Committee during the last four years.

That committee, when it commenced to function, decided that the only reasonable manner to tackle the subject was to formulate its own ideas on what were the absolutely necessary lights on an airway and at an aerodrome, and then to try and obtain international agreement with a view to suggesting later modifications to the existing international agreement.

The next line of approach was to state the fundamental requirements of each of the necessary lights.

Such advances are made from year to year in any new subject such as aviation, that if only one can standardise principles one is at least obtaining some very necessary measure of standardisation, and yet, what is more important, one is not retarding development.

Night flying has not made the progress in this country that it has in Germany and America, but, anticipating that it might progress, and as usual without any real warning, the British Committee issued last year with the approval of the Air Ministry a " Guide to Aerodrome Lighting," which one might term an intelligent anticipation of what the final specification will be.

It was hoped that the " Guide " might be useful to all authorities responsible for the organisation of aerodromes, and would give them some indication of what is really required.

The most prevalent mistake of the uninitiated is to suggest the provision of lights which, in conditions of good visibility might be sufficient in their intensity, but under conditions of bad visibility are useless, they are quite forgetful of the fact that it is under those conditions a visible light is most necessary.

One might make some reference both from a national and an international aspect, to the question as to who should provide the necessary lighting on airways and at aerodromes.

I cannot help but feel that if any country wants to attract air traffic, and in this case night air traffic, it must light its aerodromes and airways. There are instances, of course, where an air line might pass through a country and be of little use to that particular country, and in that case some special arrangement must be made.

From a national point of view it seems fair to suggest that the owners or licensees of the aerodrome should provide the necessary aerodrome lighting.

So far, in this country, all airway lights have been provided by the national Government, but I cannot say whether that practice will continue.

There is rather a tendency for operators of aircraft to look upon the providers of all lighting equipment as philanthropic institutions, but as in every other walk of life, whatever is provided has got to pay for itself either directly or indirectly.

In other words, sooner or later one has got to consider the imposition of some form of light dues based on possibly present-day marine practice. Such a suggestion seems eminently sound to me, and I cannot think of a better one.

Whether it is necessary to create some body equivalent to Trinity House for that purpose I am not prepared to say, but it is worth considering.

Any opinions expressed in this paper are to be taken as my personal opinions.

ABSTRACTS OF PATENT SPECIFICATIONS

(*Specially abstracted for the Journal by W. O. Manning, F.R.Ae.S.*)

Regular abstracts of Patent Specifications received by the Society are published in the Journal. It should be noted that these abstracts are specially compiled by Mr. W. O. Manning, F.R.Ae.S., for the Journal and are only of those actually received and subsequently bound in volume form for reference in the library. These volumes extend from the earliest aeronautical patents to date, and form a unique collection of the efforts which have been made to conquer the air.

The Council accept no responsibility whatever for the accuracy of the abstracts and in any case of doubt the full patent can be consulted when necessary in the library of the Society.

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Aerodromes

410,265. *Improvements in or Relating to Air Port Constructions.* Wood, J. W., 101, Park Avenue, City and State of New York, U.S.A. Dated January 20th, 1933. No. 1,973.

This specification describes an arrangement of an aerodrome possessing runways running in four directions, hangars, passenger accommodation and parking areas for road transport. The passenger station is arranged to accommodate aeroplanes on both sides, one side being normally for in-going and the other for out-going traffic, and arrangements are made to enable the aeroplanes to be put into position for loading by mechanical appliances and to be transferred from one side of the passenger station to the other. Claims are made for allowing vehicles to enter via a tunnel or bridge for the position of the hangars, the parking space and for intersecting runways, etc.

Aerofoils

409,133. Jutting, B. G., Post Office Box 105, Newton, New Jersey, U.S.A. Dated April 18th, 1933. No. 11,314.

The inventor proposes, instead of a propeller for the propulsion of aircraft, to drive a blower by the engine and to conduct the compressed air to channels on the leading edges of the wings. These channels possess nozzles projecting backward through which the air is emitted above and below the wings. It is stated that the upper surface of the wing is to be cambered, and the lower surface flat.

Aeroplanes—Construction

407,009. *Improvements in or Connected with Cantilever Wings for Aircraft.* Vickers (Aviation), Ltd., and Wallis, B. N., both of Weybridge Works, Byfleet Road, Weybridge. Dated September 7th, 1932.

In the case of cantilever wings for aircraft, it is known that the movement of the centre of pressure on the wing when the ailerons are operated produces a torsional force on the wing which tends to produce a torsional distortion, and that this distortion may affect seriously the lateral control. In order to obviate this difficulty it is proposed to use a wing, preferably of the single-spar type, which is so arranged that the centre of pressure of the forces caused by use of the aileron lies on or in front of the torsional axis of the wing structure. This is attained by sweeping the torsional axes of the wing structure forward, so that the outer section of the wing possesses a sweep forward. The remainder of the wing may be at right angles to the fuselage, or may also be swept forward or back. Means are described for varying the sweep forward of the wing so that this may be set to the angle found best from experiments with the actual aircraft.

406,908. *Improvements in Aerofoils for Use in the Construction of Aeroplanes and the Like.* Payne, M., 50, Hook Road, Surbiton, Surrey, and Sir J. V. Carden, Tomlin's Cottage, Frimley, Surrey. Dated July 3rd, 1933. No. 18,859.

It is proposed to construct aeroplane wings by moulding a material described as "solidified foam," and it is suggested that rubber or cellulose acetate are suitable materials for this purpose. The skin or outer surface of the wing is to be made continuous and hard, and may be reinforced by metal, by corrugating or by woven fabric.

410,405. *Improvements in and Connected with Aeroplane Wings and/or Tail Sections.* Martin, J., Martin's Aircraft Works, Higher Denham, Bucks. Dated October 20th, 1933. No. 27,090.

This specification describes a method of constructing wings or tail surfaces for aircraft in which the structure is stiffened torsionally by means of cross bracings between the spars. These cross bracings are formed of members of full spar depth and are strongly connected where they cross. These cross members are formed of channel sections when metal construction is used and the general arrangement is stated to have advantages in connection with biplanes. Wood construction may also be used, the disposition of the structural members being similar.

412,232. *Improvements in or Connected with the Construction of Wings for Aircraft.* Vickers (Aviation), Ltd., and Wallis, B. N., both of Weybridge Works, Byfleet Road, Weybridge, Surrey. Dated December 22nd, 1932, No. 36,307, and November 24th, 1933, No. 32,879.

The arrangement of wing described in this specification is of the single spar type, this spar normally consisting of upper and lower members connected by warren bracing. The normal ribs of an ordinary wing are replaced by two sets of ribs running diagonally and interconnected where they cross, these crossing ribs making a diamond pattern on the wing. This construction is claimed to provide torsion bracing and to save weight. It is also stated that the warren bracing of the spar may be omitted, enabling an outer wing to be telescoped within the main wing, thus enabling the total wing area of the aeroplane to be varied. The diagonal ribs, as shown, are without bracing connecting the upper and lower booms. Many constructional details of this type of wing are described.

410,750. *Improvements in or relating to Aeroplane Wings and like Aerofoil Structures.* The Bristol Aeroplane Co., and Pollard, H. J., both of Filton House, Bristol. Dated November 19th, 1932. No. 32,750.

This specification describes a method of bracing an aeroplane wing torsionally. It is proposed to cover the top surface of the wing with sheet metal and to arrange the usual drag bracing between the bottoms of the two spars. Alternatively, the bracing may be carried through between the bottoms of the two spars while other bracing is carried alternatively from the bottom of the rear spar to the top of the front spar, then back to the bottom of the rear spar, etc. The combination of the sheet covering and the bracing is claimed to render the wing stiff torsionally.

411,255. *Improvements relating to Fabric Bodies for Vehicles.* Marsden, L., The Shrubbery, Sir Harry's Road, Edgbaston, Birmingham. Dated March 17th, 1933. No. 8,111.

It is proposed to cover the bodies of vehicles by covering them with fabric and then spraying the fabric with metal. The fabric thus treated may be finished, if desired, by coating with cellulose or other enamel. The thickness of the metal sprayed does not interfere with the flexibility of the fabric.

411,242. *Improvements in or relating to the Construction of Aircraft Wings.* The Fairey Aviation Co., Ltd., Cranford Lane, Hayes, Middlesex, and Hollis Williams, D. L., Hillside, Swakeley's Road, Ickenham, Middlesex. Dated February 27th, 1933. No. 5,954.

It is proposed to construct wing spars for aircraft by forming the spar as a laminated structure to the opposite sides of which are secured outwardly-directed flanged marginal elements, of the sections of which the wing proper is composed. A cover plate is provided over the junction of these elements to preserve the continuity of the covering. Provision may be made for water-tight bulkheads in the wing.

412,084. *An Improved Method of Construction of Automobile Bodies and the like, such as Aeroplane and Light Sea Craft.* Boyd, H. B., 72, Hornchurch Road, Romford, Essex. Dated October 18th, 1933. No. 28,760.

It is proposed to construct the bodies of vehicles by making a framework of wood or metal and covering this structure with panels made of bakelite or some similar material, the panels being reinforced with wire gauze, etc. The panels are to be secured to the framework with studs cast in the panels, or nuts cast therein. Rubber pads are introduced for insulation purposes.

408,457. *Improvements in or Relating to Sustaining or Propelling Surfaces, Particularly Aeroplane Wing Structures.* Canova, F. P., 4, Via Mario, Giuriati, Milan, Italy. Convention date (Italy), May 4th, 1932.

In wings of bi-convex section it is stated that there is a lowering of pressure on the underside of the leading edge of the wing. In order to reduce this, it is proposed to blow air out of this part of the wing through holes in the wing, the air being conducted to the holes by an internal duct. The air is supplied through holes in the leading edge of the wing, and arrangements are made by which the quantity of air may be regulated.

Aeroplanes—Control

409,993. *Improvements in Stabilising Devices for Aircraft.* Gianoti, M. I. L., 15, Rue Louis-Phillipe, Neuelley-sur-Seine (Seine), France. Convention date (France), September 30th, 1932.

It is proposed to fit a vane to aircraft in the neighbourhood of and under the main plane, the vane having a negative angle of incidence with a spring tending to increase this negative angle. The vane is therefore forced downward by the air forces when the machine is in flight, but the angle which it would take up is controlled partially by the spring. The inventor states that the variation of the angle such a vane would take up would be in the same direction for an increase of the angle of incidence of the aircraft as for a reduction in the speed of the aircraft and in the other direction for a reduction of the incidence angle or an increase of speed. He therefore proposes to stabilise the aircraft by connecting this movable vane suitably to the elevator. Several methods are described for carrying out and arranging the device.

408,122. *Improvements in or Relating to Hydraulic or Pneumatic Rudder Steering Installations for Air or Watercraft.* Siemens and Halske Aktiengesellschaft, Berlin-Siemenstadt, Germany. Convention date (Germany), November 24th, 1932.

This specification refers to cases where the controls of an aircraft are operated by compressed air or hydraulically, the movement of the controls being effected by a piston in a cylinder, the supply of fluid to which is controlled in its turn by a servo motor apparatus controlled automatically, say by gyroscopic means. The apparatus described is for the purpose of cutting out this control entirely so that the aircraft controls can be operated manually by the pilot. This is effected by arranging a pipe between the two ends of the working cylinder in which is fitted a valve arranged to close automatically when pressure is on, thereby permitting the system to operate with power control. When the pressure is off the valve opens permitting fluid to pass between both sides of the piston and permitting manual control. Arrangements are made by which the pilot can turn off the pressure by means of a cock.

Airscrews

404,817. *Improvements in Apparatus Provided with Dynamic Lifting Surfaces or with Dynamic Lifting Propelling Surfaces, Particularly Aircraft.* Loth, W. A., and Guyot, S. M. H., 26, Avenue Charles, Floquet, Paris, France, and 1, Rue Dante, Paris, France. Convention date (France), February 20th, 1932.

This specification relates to helicopter lifting screws—not only when the screw is used solely for lifting, but also when it is used, in addition, for propulsion, and the stated object of the invention is to increase the lift and propulsion effect of such screws. It is proposed to effect this by providing the upper surfaces of the hollow rotating aerofoils with slots through which air is passed under pressure or by suction. It is proposed to provide the pressure by means of a blower in the hub of the screw, etc., and the suction by providing holes in the extremity of the blade communicating with the hollow interior, by which means it is stated that the air will be sucked out by centrifugal force. Alternatively, it is proposed to provide the rotating aerofoils with slots communicating with both upper and lower surfaces.

Autogiros

410,532. *Improvements in and relating to Aircraft having Rotative Wings.* J. de la Cierva, Bush House, Aldwych, London, W.C.2. Dated November 26th, 1932. No. 33,559.

This specification refers to aircraft of the autogyro type and has for its object the purpose of effecting the control in flight of the altitude and motion

of such an aircraft by operating on the elements of the rotor itself so as to modify its action. This controlling operation is performed by varying the geometrical pitch angles of the blades of the rotor. It is claimed that this arrangement has an advantage as the control does not involve changing the circulation of the rotational axis of the rotor hub laterally to the aircraft, which is particularly advantageous when a power drive is applied to the rotor hub. Drawings and a description of the mechanical details are given, and there are 28 claims in connection with the arrangement.

Catapults, etc.

409,937. *Improvements in or Relating to Aircraft Catapulting Apparatus.* Deutsche Werke Kiel A.G., Werftstrasse 114, Kiel, Germany. Convention date (Germany), July 18th, 1932.

This specification describes a method of bringing the movable parts of a pneumatic aircraft catapult to rest after the aircraft has been propelled. The portion of the mechanism connected with the cradle for the aeroplane is braked by means of a piston provided with leaks situated in a cylinder containing fluid, but the main piston which transmits the force of the compressed air is slowed down by means of an auxiliary piston situated in the same cylinder which is moved forward by the main piston by virtue of air pressure between them until sufficient air pressure is built up behind the auxiliary piston to cause it to come to rest. Until this latter piston is slowed down the fluid brake does not come into action.

Control of Aircraft

410,086. *Improvements in or relating to Control Arrangements for Motors, Particularly Rudder Motors.* Siemens and Halsk, Aktiengesellschaft, Berlin-Siemensstadt, Germany. Convention date (Germany), January 4th, 1933.

In the case of rudders operated by a servo motor system, operating by means of liquid pressure in a cylinder, it is stated that a resilient connection between the piston of the operating mechanism and the operating valve is normally advisable in order to enable a certain displacement of the zero position of the whole regulating device. It is stated that this resiliency is undesirable in the zero position, and a resilient mechanism is described which is intended to overcome this difficulty. This mechanism consists of a piston working in a cylinder, which piston contains a smaller piston working in a cylinder formed within the first. This smaller piston is controlled by a spring, and the passage of fluid in it is controlled by a valve. The arrangement is such that the mechanism is normally rigid, but when the piston is moved with greater force fluid is allowed to pass from one side to the other of the smaller piston, thereby giving resiliency.

411,620. *Improvements relating to Automatic Steering or Stabilising Devices, particularly for Aircraft.* Boykow, J. M., 2A, Fontonestrasse, Berlin-Lichterfelde-West, Germany. Convention dates (Germany), March 12th, 1932, and May 6th, 1932.

This specification refers to the type of apparatus known as an automatic pilot, and is intended to obviate the trouble which the inventor states occurs with the known apparatus of this type, that it is liable to produce an oscillating movement in the aircraft which it controls. In this device the gyroscope controls the making of a contact which starts the motor operating the particular control required, and this contact is also controlled by a spring and also by a damping device. A method is also described for controlling the speed of the motor by a magnetic brake. Both the brake and the spring are adjusted according to what the inventor calls the stabilising value of the aircraft. The gyroscope acts

on electrical resistances constructed either of carbon or crystal, constructed so that the force produced by the gyroscope produces an alteration in their electrical resistance, the advantage claimed being that the precessional movement of the gyroscope is very small.

411,220. *Controls for Aircraft and other Vehicles.* Dunlop Rubber Co., Ltd., 32, Osnaburg Street, London, N.W.1. Goodyear, E. F., Wright, J., and Trevaskis, H., of the company's works, Foleshill, Coventry. Dated January 31st, 1933. No. 2,960.

This specification is concerned with the dual controls fitted to aircraft for instructional purposes. The mechanism described is intended to enable the pupil to have complete control while enabling the instructor at any moment he desires to take over the control himself, either partially or wholly. The invention is described in its application to aircraft brakes. The mechanism described is suitable for employment in brake systems referred to in Specifications 379,520, 397,895, 397,896, 397,897, 398,301, and 399,622. Both the instructor's and pupil's controls are connected to the valve gear of the fluid brake system by means of Bowden cables. The outer sheath of the cable from the pupil's control is connected to a rocking lever, to the other end of which a further control is connected, the latter being operated by the instructor through a separate lever. By the operation of this lever the instructor can render the pupil's control either partially or wholly inoperative. Different arrangements of the control levers are described.

Engines

406,485. *Improvements in or Relating to Means for Use in Cooling Aircraft Motors.* Dornier Metallbauten G.M.B.H. and Dr. Ing. C. Dornier, Friedrichshafen, Lake Constance, Germany. Convention date (Germany), May 20th, 1932.

It is proposed to cool the radiator of a water-cooled aero engine by forcing through it by a fan the boundary layer of air from the wing. The motor may be fitted either in the fuselage or in or on the wing, and in each case the cooling air is drawn from openings dispersed towards the rear of the upper surface of the wing, from whence it is guided by ducts to the fan and forced through the radiator and is finally discharged into the atmosphere. The discharge may be arranged to take place through the bottom of the fuselage, through ducts provided in the trailing edge of the wing, or in any other suitable position. The fan may be driven either directly from the engine or by means of an exhaust turbine.

410,199. *Improvements in or Relating to the Cooling Systems for Internal Combustion Engines.* The Fairey Aviation Co., Ltd., Cranford Lane, Hayes, Middlesex, and Forsyth; A. G. Venlaw, Burdon Lane, Cheam. Dated September 17th, 1932, No. 25,936, and February 1st, 1933, No. 3,122.

This specification describes a method of cooling an aero engine by means of a combination of water and steam cooling. It is proposed to provide a water radiator of a size sufficient to cool the engine under normal conditions and to allow any steam generated owing to the engine becoming abnormally hot to pass to a separate condensor where it is condensed and returned to the system by a pump. Centrifugal separators can be used to assist in the separation of the steam from the water and different dispositions and types of the radiators and condensors required are described.

409,834. *Improvements in Air-Cooled Condensers for Aircraft.* Ellor, J. E., South Drive, Chain Lane, Mickleover, Derby, England. Dated December 28th, 1932. No. 36,676.

It is proposed to improve the heat dissipating property of an air-cooled aircraft condenser by fitting it with fins parallel to the direction of the airflow.

The example described fits into the leading edge of a wing. Alternatively, the fins may be boxed in, air being admitted through a slot along the leading edge of the condenser and emitted through slots at the point of junction between the condenser and the wing proper.

406,925. *Improvements in or Relating to Aircraft Engines.* The Fairey Aviation Co., Ltd., Cranford Lane, Hayes, Middlesex, and Forsyth; A. G. Venlaw, Burdon Lane, Cheam, Surrey. Dated August 8th, 1933. No. 22,196.

In cases where the reduction shaft of an aero engine is formed in one piece with the propeller hub it is necessary to arrange for the reduction gear housing to be split in order that the parts may be assembled. It is proposed in this specification to construct the propeller hub and shaft so that they fit into the interior of the reduction gear shaft, the drive between the two being taken by serrations. The two shafts are connected by a nut on the rear of the reduction gear shaft and a taper shoulder on the front end.

410,387. *Improvements in and Relating to Elastic Fluid Turbine Drives, Particularly for Aircraft.* The British Thomson-Houston Co., Ltd., Crown House, Aldwych, London, W.C.2. Convention date (U.S.A.), September 13th, 1932.

This specification describes in considerable detail a proposed arrangement of an elastic fluid turbine combined with a reduction gear intended for the propulsion of aircraft. The turbine itself is mounted on a quill shaft which telescopes the pinion shaft, the latter being attached to the quill shaft at the low pressure end of the turbine. The casings containing the turbine and reduction gear are bolted together and are arranged to be attached to the aeroplane at one ring position so that the turbine may be free to expand when heated. Numerous precautions for preventing the expansion of the turbine when hot from interfering with operation are described. It seems that steam is intended to be the operating fluid.

409,498. *Reaction Drive for Vehicular Craft.* Dr. Ing. e. h. H. Holywarth, Goethestrasse, 7, Dusseldorf, Germany. Convention date (Germany), March 30th, 1932.

The apparatus proposed consists primarily of a closed cylinder into which is injected compressed air and fuel. This mixture is exploded by a sparking plug and the products of combustion escape by a valve and are finally swept out of the cylinder by injecting further compressed air. This is again supplied with fuel and exploded by a sparking plug so that the explosions occur rhythmically. The burnt gases, which possess high temperature and pressure, pass through the blades of an exhaust turbine, the energy from which is used to partially supply the energy required for the air compressor. The rest of the energy required for the air compressor is obtained from a steam turbine plant, the heat for the generation of the required steam being obtained by passing water through jackets on the closed cylinder, the exhaust turbine, and also by superheating and other coils arranged in the path of the exhaust gases. The water used is condensed and returned to the boiler. The cooled exhaust gases then escape through a tapered nozzle which acts as the reaction propeller. Alternatively, when the speed of the vehicle is too low to permit of the reaction nozzle possessing a high propulsive efficiency, the nozzle can be cut out and the gases delivered to a further turbine which drives a propeller.

411,965. *Planetary Gearing for Transmitting the Drive from an Impulse Engine to a Rotary Element.* Armstrong Siddeley Motors, Ltd., and Viale, S. M., both of Armstrong Siddeley Works, Park Side, Coventry. Dated January 31st, 1933. No. 2,967.

This specification describes a planetary reduction gear for aero engines in which an internally toothed annulus is driven by the engine, the propeller is

driven by the planetary ring, and the reaction gear is flexibly mounted by means of spring blades and by means of a friction damping device controlled by the propeller thrust. The spring blades extend radially from a member connected with the reaction gear and engaged with the teeth of an internally toothed wheel bolted to the gear casing. A friction device on a cone seating is also provided, and means are described by which the surfaces are forced further together by the increased propeller thrust as the engine speed increases, therefore increasing the damping effect. An auxiliary damping device is also provided, and there is also a provision for taking the drive in the event of a failure of the springs.

Flying Boats

408,165. *Improvements in or Relating to Flying Boats.* Edward G. Budd Mfg. Co., 2500, Hunting Park Avenue, Philadelphia, Pennsylvania, U.S.A. Convention date (U.S.A.), May 12th, 1932.

This specification describes a method of constructing flying boat hulls and has special reference to a structure containing sheet metal structural forms especially adapted to being joined by spot welding and refers specially to the deck construction. This part is formed of downward facing channel sections forming deck beams and also deck longitudinals of similar form. These are joined by flat segment-shaped metal plates and the beams and longitudinals are joined by spot welded channel section knees.

407,835. *Improvements in or Relating to Flying Boats.* Edward G. Budd Manufacturing Co., 2500, Hunting Park Avenue, Philadelphia, Pennsylvania, U.S.A. Convention date, May 12th, 1932.

It is proposed to construct the fin of a flying boat in metal by utilising a number of vertical members extending from beams attached to the side keelsons of the hull. These members carry longitudinal members corresponding to the streamline section desired and the whole is completed by edge members of channel section. The arrangement is so designed as to be suitable for spot welding.

Fuselages

404,606. *Improvements in or Relating to Aircraft Fuselages and Aircraft Motor Gondolas.* Dornier Metallbauten G.M.B.H. and Dornier, C., both of Friedrichshafen, Lake Constance, Germany. Dated April 15th, 1932. No. 10,875. Complete not accepted.

It is stated that the ordinary method of manufacturing aircraft fuselages leads to serious delay in the time taken for the construction, as it is not possible to proceed with the covering until the fuselage itself has been completed. The number of men employed on this work is also limited by the space available. It is proposed to obviate this difficulty by constructing the fuselage covering in the form of separate panels, which can be stiffened by means of a lattice bracing, etc., and which can be covered with sheet metal, fabric, etc., as desired. These panels are constructed separately and can be attached to the fuselage members by various methods which can be arranged so as to make them to be easily detached. It is proposed to attach them by a form of U-bolt passing round the fuselage members, by a bolt passing through the fuselage member itself, or by a clamping device resembling a turn-buckle.

Gliders

411,063. *An Engineless Monoplane or Glider Manually Propelled.* Hayes, R., Marley, Borris, Co. Carlow, Irish Free State.

This specification describes a monoplane intended to be propelled by a pedal gear operated by the pilot and attached by gearing to an airscrew. The pilot

sits inside a fuselage and a steerable tail wheel is provided. The four main members of the fuselage are disposed diamond-wise and are of streamline form.

Helicopters

406,971. *Improvements in and Relating to Helicopters.* Nishi, N., 878, Ovaza Kimüdera Kimüdera-mura, Kaiso-gun, Wakayama-ken, Japan, and Imajo, K., 211, Ikejiri Setagaya-machi, Ebara-gun, Tokyo-fu, Japan. Dated May 30th, 1932.

This apparatus consists of an annular ring shaped somewhat like a saucer, but the radial section through the ring is similar to that of a normal aerofoil. Situated in the centre of the ring is a blower driven by a vertical shaft which emits air circumferentially over the top and bottom surface of the ring. In this manner, it is stated, vertical lift can be obtained efficiently. It is also proposed to propel a machine with this apparatus by means of a separate propeller.

412,487. *Improvements in or relating to Aircraft of the Helicopter Type.* Dr. Ing. Claude Dornier, Friedrichshafen, Lake Constance, Germany. Convention date (Germany), January 26th, 1933.

This specification refers to a helicopter lifting screen which is rotated by the reaction caused by compressed air being ejected from orifices near the blade tips. It is stated that it is not necessary for every blade to be driven in this way, and that those blades which are unprovided with air passages and orifices can be made thinner in section and therefore more efficient. These blades may be in a different plane to the driven blades. In the driving arrangement described, the air is collected from the nose of the fuselage of the aeroplane and impelled into the driving blades by a fan or air-pump driven by the engine. Drawings and descriptions are given showing certain blades hinged or mounted on universal joints.

410,747. *Improvements in Aircraft.* Jean-Michel Lado-Bordowsky, 21, Rond Point de la Reine, Boulogne-sur-Seine, Paris, France. Convention date (France), November 17th, 1931.

This specification refers to a form of helicopter in which the lifting screws are driven in opposite directions and are so placed that the axes converge upwardly, the size of the screws and their angle of convergence being so determined that a negative coefficient of drag obtains. These lifting screws are fitted below the plane on each side of the fuselage in an aeroplane of normal monoplane form driven by a tractor propeller, and the speed of the lifting screws can be controlled by the pilot and they may be allowed to windmill if desired. Curves are given, stated to show the aerodynamical advantage of this combination.

Instruments

397,166. *Improvements Relating to Means for Indicating the Height of Aircraft, Particularly for Use when the Aircraft is Landing.* Lucking, D. F., Tregenna, Queen's Road, Felixstowe, Suffolk. Dated January 20th, 1932. No. 1,799.

This specification describes a proposed method of assisting the pilot of an aircraft to land under conditions of bad visibility by indicating to him his exact height above the ground. A weight attached to a cord, or similar device, is attached to the aircraft which is so arranged that it operates a special mechanism when the weight is dragged by coming in contact with the ground. It will be understood that the height of the aircraft above the ground at this point is known. The special mechanism consists, usually, of a cock which is normally open but which is closed when the weight touches an obstacle. The cock, when open,

short circuits a sensitive altimeter which, therefore, comes into action on the closing of the cock and indicates the exact height of the aircraft on a special dial.

407,819. *Improvements in and Relating to Velocity Measuring Apparatus.* British Thomson-Houston Co., Ltd., Crown House, Aldwych, London, W.C.2; Heinz, W. B., 314, Fifth Street, Scotia, Schenectady, New York, U.S.A. Convention date (U.S.A.), February 25th, 1932.

In order to produce a speed-measuring device for aircraft, the accuracy of which is independent of the density of the air, it is proposed to suspend a body, say a cylinder, so that it is able to oscillate in a direction at right angles to the direction of motion of the machine. This oscillation is produced by the formation of vortices and it is stated that the frequency of the oscillation is dependent solely on the velocity of the air. The air speed is measured with the aid of an electrical instrument which is influenced by the oscillation so as produce a current whose magnitude is proportional to the frequency of the oscillation. Modifications of the method are described and the oscillating member may be mounted inside a venturi tube.

Miscellaneous

406,477. The Fairey Aviation Co., Ltd., Cranford Lane, Hayes, Middlesex, and Williams, D. L. H., Hillside, Swakeley's Road, Ickenham, Middlesex. Dated February 27th, 1933.

This specification describes a method by means of which a bomb, or the like, may be loaded into a bomb cell in an aircraft without manhandling. In the form of the invention selected for description, the bomb cell is in the wing and the bomb is lifted by a winch fitted on a ladder which rests on the ground and against the leading edge of the wing. The rope from the winch passes over pulleys fitted on the top of the ladder and over the bomb cell, whence the rope passes to a frame carrying the bomb which is hinged to rods from its forward end and which can be swung up into the wing. Adjustments to the bomb release, etc., can be made before the bomb is drawn up into its cell.

406,713. *Improvements in or Relating to a Method and Means for the Propulsion of Aircraft.* Campini, S., 3, Viale Cossica, Milan, Italy. Dated July 30th, 1932. No. 22,000.

This specification describes a method propelling an aeroplane by means of a jet of air. The air may be drawn into the fuselage through an annular ring fitted round the fuselage, and is then compressed by compressors driven by the motor. It then passes through the engine radiator and is further heated by heaters burning fuel in order to increase its volume, and therefore its velocity, before being ejected through a large jet at the rear of the fuselage. Several modifications of the main scheme are described.

Parachutes

410,361. *Improvements in and Relating to Parachute Pack and Chair.* Switlik, S., Broad and Dye Streets, Trenton, Mercer, New Jersey, U.S.A. Dated August 4th, 1933. No. 21,963.

It is proposed to provide a parachute pack which is carried by the chair provided for the use of passengers in passenger aircraft, the purpose being to insure that the parachute is always available for the use of passengers. The passenger can leave the chair with the harness or with the parachute pack as well. When the parachute is removed from the chair the back collapses so as to reduce the difficulty of passengers leaving the machine in an emergency.

Seaplanes

409,019. *Improvements in or Relating to Undercarriages for Seaplanes, Amphibian Aeroplanes and Similar Aircraft.* Fairey, C. R., Cranford Lane, Hayes, Middlesex. Dated January 13th, 1926. No. 1,009.

This specification refers to an aircraft possessing both landing skids and floats, the floats, when in use, being fitted under the skids. It is proposed to arrange that the floats may be dropped while the aircraft is in flight so that deck landing may be carried out on the skids. The chassis is of the type described in Patent No. 228,245, and the float is normally attached on the front by a forward-projecting hook and at the rear by a movable pin engaging in lugs attached both to the chassis and the float. Arrangements are made so that the float or floats may be released by a single movement of a lever operated by the pilot and attached to the movable pin. Alternative methods of construction are described.

Signalling

407,826. *Improvements in and Relating to Sound Wave Systems.* British Thomson-Houston Co., Ltd., Crown House, Aldwych, London, W.C.2. Convention date (U.S.A.), March 16th, 1932.

This specification deals with a method of construction of sound producing apparatus and a method of arranging it so that the locality of an aerodrome may be apparent to an in-coming aeroplane under conditions of poor visibility. The sound producing apparatus may consist of three megaphones situated side by side and containing within each megaphone a high frequency whistle. The apparatus is arranged so as to throw a fan-shaped zone of sound vertically; the sound waves may be modulated if desired. These appliances are placed normally on the boundaries of the aerodrome and are arranged so that the sound produced by them intersect at a known height above the aerodrome. The aeroplane is fitted with a receiving megaphone and the sound waves are taken via an acoustic filter to a stethoscope worn by the pilot of the aeroplane. It is stated that by the difference in the signals heard the pilot can determine his location with reference to the aerodrome.

Undercarriages

409,163. *Improvements in or Relating to Aircraft such as Aeroplanes and the Like.* Boggio, A., 17, Via Insegnamente, Milan, Italy. Dated July 4th, 1933. No. 18,942.

It is proposed to obtain the power required for the operation of brakes on the landing wheels of aircraft from the rotation of the tail wheel. This is effected by arranging a friction pad fitted within the tail wheel so that it can be forced into contact with a brake drum on the tail wheel by means of a lever operated by the pilot. When this is done the friction pad will tend to be pulled round the wheel and it is the force resulting from this action that it is proposed to use for the operation of the landing wheel brakes. The connections may be made by means of Bowden wires, hydraulically or pneumatically, and arrangements may be made for differential braking on the landing wheels for steering purposes.

409,456. *Improvements in or Relating to Control Systems or Brakes for the Wheels of Aircraft.* The India Rubber, Gutta Percha and Telegraph Works Company, Ltd., Aldwych House, Aldwych, London, W.C.2, and Tarris, F. J., of the Company's Works, Silvertown, London, E.16. Dated January 4th, 1933. No. 261.

This specification describes a method by which wheel brake control mechanisms may be applied to both control positions of a dual controlled aero-

plane, and by which the pilot operating from one control position can cut out the wheel brake operating gear from the other control position while still retaining wheel brake control himself. The system is thus suitable for an instructional aircraft on which those occupying the control positions are the instructor and pupil. The brakes are operated by fluid pressure or vacuum, the pressure being obtained from pedal-operated pistons connected to the system through a special valve. In the case of fluid pressure operation the means for cutting out the second control gear consists of a valve allowing the brake pressure generated by the operation of this control to pass into a reservoir where it is retained until the pedals of this control are allowed to return to a position of rest.

408,435. *Improvements in or Relating to the Undercarriages of Aircraft.* The Fairey Aviation Co., Ltd., Cranford Lane, Hayes, Middlesex, and Williams, D. L. H., Hillside, Swakeley's Road, Ickenham, Middlesex, and Churnley, J. S., Beaumaris, North Hyde Road, Hayes, Middlesex. Dated February 27th, 1933. No. 5,958.

This specification describes a folding chassis for aircraft in which the landing wheel is carried in a fork supported by a diagonal member running aft. The folding is effected by pivoting the fork containing the wheel at some point above the wheel and rotating the fork backwards from this point. The diagonal member is got out of the way by burying it in the middle and arranging to break the hinge before backward movement takes place. The arrangement described shows the apparatus operated by a cylinder and piston operated by compressed air. This is arranged to rotate the shaft carrying the fork pivot by means of a crank, but means are provided for obtaining a small movement of the sleeve carrying the crank before the shaft is rotated, this small movement being utilised to operate the locking pin of the hinge of the diagonal member. Shock-absorbing mechanism is provided for.

412,191. *An Improved Damping and Suspension Device for Landing Gears of Aeroplanes.* Messier, Y. L., 179, Boulevard Brune, Paris, France. Convention date (France), December 24th, 1932.

In the case of telescopic legs for undercarriages, it is often necessary to prevent the piston rod turning with respect to the cylinder. This is usually effected by means of keys or feathers, but it is proposed, in this specification, to do this by boring two eyes, one each on the piston rod and cylinder, and connecting these together by two links. These links are hinged together and the free ends of each are hinged to the eyes, the arrangement of the links being in the form of a V.

411,875. *Improvements in or relating to Aircraft Undercarriages.* The Bristol Aeroplane Co., Ltd., and Frise, L. G., both of Filton House, Bristol. Dated December 15th, 1932. No. 35,580.

In aircraft used for the transport of passengers it often happens that the door which permits ingress into the fuselage is at a considerable height above the ground when the machine is at rest, thereby making access to this door difficult. It is proposed to obviate this difficulty by arranging for the chassis to be retracted while the machine is on the ground, thereby bringing the door nearer the ground level. The chassis is raised to the flying position before the machine takes off. The mechanism described consists of a screw carrying a nut to which the oleo leg of the chassis is attached. This screw is rotated by a worm gear driven either electrically or manually. Alternatively, it is proposed to raise the chassis to the flying position while the aircraft is taxying. This is accomplished by pumping fluid into the oleo leg by a pump actuated from the landing wheel.

CORRESPONDENCE

(The following contribution to Mr. North's lecture was inadvertently not printed in the July Journal, and is here printed in the form of correspondence.)

Townend Rings on Pusher Engines

To the Editor of the Journal of the Royal Aeronautical Society.

Dear Sir,—I should be glad if Mr. North would add whatever facts of a quantitative nature he can to his remarks under the above heading. It would appear to me that, apart from the possible increase in cooling, the reduction in drag would result only from maintaining a non-turbulent air flow on the body immediately ahead of the ring. If this conception is correct, then I should expect the reduction in drag to be very small indeed, say, of the order of five per cent. I should expect the performance of the pusher airscrew to be noticeably improved by the action of the ring and should be glad if Mr. North would confirm this, or otherwise.

Townend Rings.—Because the ring acts as an aerofoil, its attitude on tractor machines gives it a considerable forward force component under high speed conditions (250 m.p.h. and over). Also, I understand from the N.A.C.A. tests that the fore and aft position is not sensitive to positions of 4″-5″ on a 600 h.p. radial engine. Hence, it has occurred to me that here we have a source of energy which, so far as I know, has hitherto not been tapped, for, if the ring were suitably mounted on slides, or linkages, one could begin with the ring in a back position and allow the forward travel to do work, when the ring was allowed to move forward. For the ring under consideration, I should estimate the energy available would be of the order of 4,000-5,000 lbs. ins., which might be utilised for assisting to retract the undercarriage or for automatically controlling wing flaps and the like. I should be glad to know Mr. North's opinion on the practicability of such an application.

Yours faithfully,

F. Radcliffe.

Dear Sir,—In answer to Mr. Radcliffe, the figure of 40 per cent. reduction on a pusher nacelle has already been quoted, and probably much better results could be obtained with a nine-cylinder engine and a careful study of the best form of nacelle shape. The ring has the effect of correcting the divergent air stream which these cylinders tend to set up. I am not aware of any experimental results on the effect on performance of pusher airscrews, but I am doubtful if there are any general grounds for expecting an abnormal increase in nett propulsive efficiency. Mr. Radcliffe's proposal for using a ring as a source of energy is ingenious, but it appears to me that the practical disadvantages and complications of the mechanism involved would make one hesitate in attempting to make use of this energy.

Yours faithfully,

J. D. North.

REVIEWS

Pilot's "A" Licence

By John F. Leeming. Published by Pitman. Price 3/6.

It is a matter for note that this little book has reached its sixth edition. It contains just the information that the embryo pilot requires, given clearly and lucidly so that there is no possible excuse for the procedure being misunderstood.

The greater part of the book is concerned with the examination, and no one who reads this part of the book intelligently should fail to pass. Such mysteries as the reason for the carrying of two black balls by a dirigible, or what is the regulation lighting for a kite aloft at night, are clearly explained, as well as the more obvious matters which concern the normal air tourist.

This is a most useful book and should be read by everyone who is learning to fly.

British Airways

C. St. J. Sprigg. Published by Nelson. Price 2/6.

This book has been written for the purpose of informing the general public about airways, what they do, the type of men who run them, the aeroplanes they use, and the developments that are likely to happen in the future.

Mr. Sprigg is a well-known writer on aeronautical matters, and he has produced a book which is admirably suited to those who, knowing nothing of aviation, desire to acquire a little knowledge about it in a form which is easy to read. Only one mistake has been noticed, the Avro 10 does not possess a fuselage made of iron tubing coated with steel. The book ought to command a ready sale among the general public.

Inspection of Aircraft after Overhaul

S. J. Norton. Published by Sir Isaac Pitman and Sons, Ltd. Price 3/6.

This book is one of a series published for the purpose of assisting ground engineers to pass the examinations for their various grades, and it fulfils its purpose excellently. The first chapter deals with non-metallic materials, including timber, fabric, paints and varnishes, dopes, etc., and is well written. An explanation of what is meant by such expressions as "dote" and "shakes," when dealing with timber, might be added with advantage.

The second chapter is concerned with metallic materials, and the subject is explained clearly with many practical hints; the subject of silver soldering is, curiously, not mentioned. The third chapter is more general, treating such matters as splicing and general components, and the book concludes with chapters on hulls and floats, rigging and installations, etc., on completed aircraft, and a glossary of aeronautical terms.

This little book should be most useful to ground engineers and others concerned in the practical operation of aircraft.

The Rigging, Maintenance and Inspection of Aircraft

By W. J. C. Speller. Published by Sir Isaac Pitman and Sons, Ltd. Price 5/-.

This book is intended for the use of ground engineers in the "A" category, and contains a quantity of information on matters concerning their work. There are chapters dealing with Assembly and Rigging of Aircraft, Defects and Deterioration in Materials, Seaplanes and Flying Boats, Instruments and Electrical Installations, and there is a useful appendix which includes an article on the Law relating to Civil Aviation, by A. McIsaac.

The series of works for ground engineers, to which this book belongs, is written mainly for examination purposes, but they contain an immense amount of practical information based on experience. Those who are concerned with the maintenance and upkeep of aircraft will find these books of great assistance.

The Scarlet Angel

By Alban Ali. Published by Duckworth. Price 10/6.

This book describes the adventures of the author in an attempt to fly from India to England on a Comper Swift with a 75 h.p. Popjoy engine. The flight was not uneventful, and after several forced landings, on two of which the aeroplane was damaged, the journey had to be abandoned at Cairo as the engine needed a complete overhaul.

The book contains some interesting information as it describes the difficulties of flying in the more remote parts of India, where there are no regular aerodromes and where polo grounds have to be used. These are often difficult to get into and of insufficient size. The author is a keen observer and has much to say about native customs.

Generally the book is well written, but the narrative is marred by the use of many phrases which, however suitable they may be for ordinary conversation, are completely out of place in a book of this type. It will make an appeal to those who are interested in the adventurous side of flying.

The 578th Lecture delivered before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

TWENTY-SECOND WILBUR WRIGHT MEMORIAL LECTURE

The Twenty-second Wilbur Wright Memorial Lecture, entitled "Stalling," by Professor B. Melvill Jones, A.F.C., M.A., F.R.Ae.S., was delivered before the Society on Thursday, May 31st, 1934, at 9.15 p.m., in the Aeronautical Section of the Science Museum, South Kensington, before a distinguished company of members and guests.

The chair was taken by Mr. C. R. Fairey, M.B.E., F.R.Ae.S., President of the Society. The function was held at the Science Museum by kind permission of the Director, Lieut.-Colonel E. E. Mackintosh, D.S.O.

The lecture was preceded by the annual Council Dinner at which the following were present:—

C. R. Fairey, Esq., M.B.E., F.R.Ae.S., President of the Society, in the chair.

GUESTS.

The Right Hon. Lord Amulree, P.C., G.B.E., K.C.
Major B. F. S. Baden-Powell, F.R.A.S., F.R.Met.S., Hon. F.R.Ae.S.
Griffith Brewer, Esq., Hon. F.R.Ae.S.
Sir Harry Brittain, K.B.E., C.M.G.
His Excellency Baron E. de Cartier de Marchienne, Belgian Ambassador.
A. E. L. Chorlton, Esq., O.B.E., M.P., M.Inst.C.E., M.I.Mech.E., F.R.Ae.S., President, Institution of Mechanical Engineers.
Captain M. J. B. Davy, A.F.R.Ae.S.
Air Vice-Marshal Sir Hugh Dowding, C.B., C.M.G., Air Member for Supply and Research.
Lord Gorell, C.B.E., M.C., Chairman, Royal Aero Club.
Professor B. Melvill Jones, A.F.C., M.A., F.R.Ae.S.
Lieut.-Colonel E. E. Mackintosh, D.S.O., Director, Science Museum.
Captain J. W. Monahan, American Air Attaché (Military).
Emile Mond, Esq.
Sir Joseph Petavel, K.B.E., D.Sc., F.R.S., F.R.Ae.S., Director, National Physical Laboratory.
Captain H. C. Rawlings, D.S.O., R.N., Director, Naval Air Division.
H. J. Thomas, Esq., Chairman, Society of British Aircraft Constructors.

COUNCIL.

Captain P. D. Acland.
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Lawrence A. Wingfield, Esq., M.C., D.F.C., A.R.Ae.S.I.
Captain J. Laurence Pritchard, Hon. F.R.Ae.S. (Secretary).

Immediately following the reading of the lecture the Society held a Conversazione in the Science Museum, at which a very large number of the Society's members and friends and many distinguished guests were present. During the evening, by kind permission of the Air Council, the band of H.M. Royal Air Force, conducted by Flight Lieutenant R. P. O'Donnell, M.V.O., played selections. The following is a list of those who attended the Conversazione and the Lecture, in addition to the Council and their guests:—

Horace Adams, Esq.; Mrs. Horace Adams; Capitaine de Corvette Albertas (French Air Attaché); Madame Albertas; J. G. Allen, Esq.; Miss D. Allmand; Major-General R. Ando (Japanese Military Attaché); Engineer-Commander Natal Arnaud (Brazilian Naval Attaché); Madame Arnaud; the Hon. Blanche Arundell.

E. C. A. Backhaus, Esq.; Miss M. J. Baillie; Major C. J. P. Ball, D.S.O., M.C., A.F.R.Ae.S.; F. Rodwell Banks, Esq., O.B.E., F.R.Ae.S.; Mrs. Rodwell Banks; Miss F. Barwood; H. Bateman, Esq., A.F.R.Ae.S.; P./O. R. D. Baughan; Her Grace the Duchess of Bedford, D.B.E.; F. C. Behenna, Esq.; A. E. Bingham, Esq., A.M.I.Ae.E.; Mrs. Bingham; W. G. Bird, Esq., M.A., A.F.R.Ae.S.; Miss M. E. Blackburn; Colonel L. V. S. Blacker; G. R. C. Blowers, Esq.; F. G. Boreham, Esq., A.R.Ae.S.I.; Mrs. M. Boreham; Air Vice-Marshal F. W. Bowhill, C.M.G., D.S.O. (Air Member for Personnel); W. B. Dixon Box, Esq.; Miss Frances B. Bradfield, A.F.R.Ae.S.; C. Griffith Brewer, Esq., M.A., A.F.R.Ae.S.; Group Captain E. F. Briggs, D.S.O., O.B.E., F.R.Ae.S.; Mrs. E. F. Briggs; Captain J. C. Briggs; Mrs. J. C. Briggs; Wing Commander Vernon S. Brown, M.A., F.R.A.S., A.F.R.Ae.S.; Mrs. Vernon Brown; Major G. P. Bulman, O.B.E., B.Sc., F.R.Ae.S.; Mrs. G. P. Bulman; G. M. Buxton, Esq.; Captain L. C. Bygrave, M.B.E., F.R.Ae.S., A.M.I.E.E.

Brigadier-General W. B. Cadell; J. D. Campbell, Esq., B.Sc., A.R.T.C., A.F.R.Ae.S.; Mrs. J. D. Campbell; Miss Cannon; Mrs. R. S. Capon; Major B. C. Carter, M.I.Mech.E., A.R.C.Sc., D.I.C., F.R.Ae.S.; Mrs. B. C. Carter; John Carter, Esq.; Wing Commander T. R. Cave-Browne-Cave, C.B.E., M.I.Mech.E., M.Inst.N.A., F.R.Ae.S.; Major R. A. Chalmers; Air Commodore J. A. Chamier, C.B., C.M.G., D.S.O., O.B.E., A.F.R.Ae.S.; Mrs. J. A. Chamier; Professor S. Chapman, F.R.S. (President, Royal Meteorological Society); Miss L. Chitty, F.R.Ae.S.; Herbert Chitty, Esq., F.S.A.; Senor Juan de la Cierva, F.R.Ae.S.; R. M. Clarkson, Esq., A.F.R.Ae.S.; — Chronander, Esq.; J. B. S. Coats, Esq.; Mrs. J. B. S. Coats; Squadron Leader S. N. Cole, A.F.R.Ae.S.; W. S. Coleman, Esq.; H. Constant, Esq., M.A., A.F.R.Ae.S.; O. H. Corble, Esq.; Mrs. O. H. Corble; Miss G. Cottrell; Air Commodore C. L. Courtney, C.B., C.B.E., D.S.O. (Director of Training, Air Ministry); H. Roxbee Cox, Esq., Ph.D., D.I.C., B.Sc., A.F.R.Ae.S.; Mrs. D. M. Roxbee Cox.

R. W. Dana, Esq., O.B.E. (Secretary, Institution of Naval Architects); Mrs. R. W. Dana; Mrs. M. M. Dasnieres; Mrs. M. J. B. Davy; Graham Dawbarn, Esq., M.A., F.R.I.B.A., M.I.Struct.E., A.F.R.Ae.S.; Mrs. Graham Dawbarn; W. C. Devereux, Esq., A.F.R.Ae.S.; Mrs. W. C. Devereux; G. P.

Douglas, Esq., M.C., D.Sc., A.F.R.Ae.S.; Mrs. Douglas; J. Dower, Esq., M.A., A.R.I.B.A. (Secretary, Aerodromes Advisory Board); Mrs. John Dower; M. A. Doyle, Esq., B.Sc., A.F.R.Ae.S.

H. Stanley Ellis, Esq.; Mrs. E. C. Gordon England.

A. Fage, Esq., A.R.C.Sc., F.R.Ae.S.; A. L. Fairbank, Esq.; D. W. L. Fairbank, Esq.; V. M. Falkner, Esq., A.F.R.Ae.S.; Mrs. V. M. Falkner; Lieut.-Colonel L. F. R. Fell, D.S.O., O.B.E., M.I.Mech.E., F.R.Ae.S.; Mrs. D. M. D. Fell; Captain E. Trigona della Floresta (Italian Air Attaché); H. W. Franklin, Esq., B.A., A.F.R.Ae.S.; F./O. J. M. Freeman; W. S. Farren, Esq., M.B.E., M.A., F.R.Ae.S.; Edward G. Fischeles, Esq.; Captain A. G. Forsyth, O.B.E., M.C., D.F.C., M.A.(Oxon), A.R.Ae.S.I.; Mrs. A. G. Forsyth; B. M. Foster, Esq.

Group Captain A. G. R. Garrod, A.R.Ae.S.I.; Mrs. A. G. R. Garrod; Mrs. L. F. Garrod; V. S. Gaunt, Esq., A.M.I.Ae.E.; Eric C. Gibbons, Esq., A.F.R.Ae.S.; Mrs. Eric C. Gibbons; H. R. Gillman, Esq., A.F.R.Ae.S. (Secretary, Society of British Aircraft Constructors); Mrs. H. R. Gillman; H. Glauert, Esq., M.A., F.R.S., F.R.Ae.S.; Mrs. H. Glauert; A. G. Gooch, Esq.; Miss M. Green; C. G. Grey, Esq. (Editor, *The Aeroplane*); Mrs. C. G. Grey; P. T. Griffith, Esq., A.F.R.Ae.S.; Mrs. Griffith; Miss G. Gurd; G. W. T. Gray, Esq.

Major F. B. Halford, F.R.Ae.S.; Mrs. A. H. Hall; Mrs. J. R. Hall; F. Handley Page, Esq., C.B.E., F.R.Ae.S.; Mrs. F. Handley Page; J. A. G. Haslam, Esq., M.C., D.F.C., M.A., A.F.R.Ae.S.; Captain Geoffrey de Havilland, O.B.E., A.F.C., F.R.Ae.S.; Courtney Haydon, Esq.; Mrs. Courtney Haydon; R. M. Helsdon, Esq., B.Sc.; R. C. B. Hendy, Esq., A.M.I.Ae.E.; Dr. A. G. Hewer; Mrs. A. G. Hewer; M. Herrod-Hempsall, Esq.; Captain G. T. R. Hill, M.C., M.Sc., F.R.Ae.S.; Mrs. G. T. R. Hill; Mrs. L. Hinshelwood; John O. Hinks, Esq.; E. Hinks, Esq.; Mrs. E. Hinks; Mrs. J. E. Hodgson; J. L. Hodgson, Esq., B.Sc., M.I.Mech.E., A.M.Inst.C.E., A.F.R.Ae.S.; Mrs. J. L. Hodgson; A. F. Houlberg, Esq., A.M.I.Ae.E.; Group Captain T. E. B. Howe, A.F.C.; Dr. Hudson; Miss Hudson; P. V. Hunter, Esq., C.B.E. (President, Institution of Electrical Engineers); Miss Hunter.

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Thurstan James, Esq.; Mrs. Thurstan James; Mrs. James; Miss Jarrold; Mrs. Melvill Jones; Miss Melvill Jones.

W. Kaeppeli, Esq.; Mrs. D. H. Kennedy; Miss Kennedy; F. R. B. King, Esq.; P. F. King, Esq.; E. P. King, Esq., B.Sc., A.F.R.Ae.S.; Mrs. E. P. King.

Dr. G. V. Lachmann, A.F.R.Ae.S.; Mrs. G. V. Lachmann; Dr. H. R. Lang (Secretary, Institute of Physics); Mrs. H. R. Lang; W. H. Lewis, Esq., B.Sc., A.C.G.I., A.F.R.Ae.S.; Gerald Lyon, Esq., M.Sc., A.F.R.Ae.S.

Lieut. P. McCormack, B.E.; Dr. E. B. MacGinty; J. W. Maccoll, Esq., B.Sc., Ph.D., A.F.R.Ae.S.; D. Mahmoud-Bey, Esq.; Group Capt. P. C. Maltby, D.S.O., A.F.C.; Wing Commander R. Marsden; Mrs. R. Marsden; A. E. Marsh-Hunn, Esq.; Miss E. G. Mason; Sir Henry Maybury, G.B.E., K.C.M.G. (President, Institution of Civil Engineers); F. W. Meredith, Esq.; Count Roman Michalowski (Secretary, Polish Embassy); Mrs. Monahan; Mrs. Emile Mond; H. H. Morris, Esq.; Mrs. H. H. Morris; J. T. Morton, Esq., A.F.R.Ae.S.; F. W. Musson, Esq., B.A., A.F.C., A.F.R.Ae.S.; Mrs. F. W. Musson; N. S. Muir, Esq., B.Sc., A.M.I.M.E.

P. P. Nazir, Esq., M.Inst.B.E., A.F.R.Ae.S.; J. L. Nayler, Esq., M.A., F.R.Ae.S.; Mrs. Nayler; Captain D. Nicolson, A.F.R.Ae.S.; Mrs. D. Nicolson; Miss Rosalind Norman; Miss V. E. Norman; J. D. North, Esq., F.R.Ae.S., F.R.Met.Soc.

Captain E. Oberg (Swedish Naval Attaché); Madame Oberg; Engineer Lieut.-Commander S. Ochiai (Japanese Naval Attaché); E. Ower, Esq., B.Sc., A.C.G.I., F.R.Ae.S.; Mrs. E. Ower; Lieut.-Colonel M. O'Gorman, C.B., D.Sc., M.Inst.C.E., M.I.Mech.E., M.I.E.E., M.I.A.E., F.R.Ae.S.

J. H. Payne, Esq., B.Sc.; G. Pepler, Esq.; Mrs. G. Pepler; E. W. Percival, Esq., M.I.Ae.E.; Sir Ernest Petter; Lady Petter; W. E. W. Petter, Esq.; Mrs. W. E. W. Petter; Monsieur M. Peyrot; Major C. E. S. Phillips, O.B.E., F.R.S.E. (Secretary, Royal Institution); Mrs. Phillips; R. F. R. Pierce, Esq.; Mrs. R. F. R. Pierce; C. A. Pike, Esq., A.F.R.Ae.S.; Mrs. C. A. Pike; Ernest Pitman, Esq.; the Hon. I. J. Pitman; the Hon. Mrs. I. J. Pitman; Haviland Platt, Esq.; R. A. Powell, Esq., A.F.R.Ae.S.; S. G. H. Powell, Esq.; Press Association; Flight Lieut. R. C. Preston, A.F.C., A.M.I.Ae.E.; Mrs. R. C. Preston; Mrs. J. Laurence Pritchard; Mrs. D. R. Pye.

Mrs. Rawlings; A. E. Rayner, Esq. (Assistant Secretary, Institution of Electrical Engineers); Squadron Leader C. A. Rea, A.F.C., A.M.I.Mech.E., A.F.R.Ae.S.; Mrs. C. A. Rea; S. C. Redshaw, Esq., A.F.R.Ae.S.; Flight Lieut. R. W. Reeve, D.F.C., M.M.; Mrs. R. W. Reeve; Lieut.-Colonel J. D. K. Restler, O.B.E., M.Inst.C.E., M.Inst.Mech.E., F.R.Ae.S.; Mrs. J. D. K. Restler; Reuters; H. R. Ricardo, Esq., B.A., F.R.S., A.M.Inst.C.E., F.R.Ae.S.; Mrs. H. R. Ricardo; Miss A. E. Ricardo; Dr. Margaret Ritchie; C. H. Roberts, Esq.; E. W. Roberts, Esq.; B. G. Robbins, Esq. (Secretary, Institution of Automobile Engineers); Mrs. Robbins; E. B. Robinson, Esq., A.F.R.Ae.S.; Miss C. Robinson; R. J. Robinson, Esq.; A. Ryan, Esq., M.Sc.; A.F.R.Ae.S.; Lieut.-Colonel R. S. Ryan, C.M.G., D.S.O.

D. H. Sadler, Esq., M.A.; Miss C. D. Saklatvala; Mrs. W. P. Savage; R. J. Schmidt, Esq., B.Sc., Ph.D.; John E. Serby, Esq., B.Sc., B.A., A.M.I.E.E.; Mrs. Serby; P./O. K. G. Seth-Smith; Sir John Seymour-Lloyd, K.C., K.B.E., C.M.G.; Lady Seymour-Lloyd; E. Colston Shepherd, Esq. (*The Times*); Mrs. E. Colston Shepherd; Miss H. G. Shone; Major B. W. Shilson, O.B.E., A.F.R.Ae.S.; L. F. G. Simmons, Esq., M.A., A.R.C.Sc., A.F.R.Ae.S.; Mrs. L. F. G. Simmons; F. R. Simms, Esq., M.I.Mech.E., M.I.A.E., M.I.Ae.E.; Mrs. F. R. Simms; Mr. Smith-Pert; Mrs. Smith-Pert; Lieut.-Colonel S. Heckstall Smith, F.R.Ae.S.; Prof. R. V. Southwell, M.A., F.R.S., M.I.Mech.E., F.R.Ae.S.; Mrs. R. V. Southwell; Stanley Spooner, Esq. (Editor, *Flight*); Monsieur D. Steen (Counsellor, Norwegian Legation); Madame Steen; A. V. Stephens, Esq., B.A.; Major C. J. Stewart, O.B.E., M.I.Mech.E., F.R.Ae.S.; Mrs. C. J. Stewart; H. J. Stieger, Esq., D.I.C., A.F.R.Ae.S.; Mrs. T. Stieger; Captain R. H. Stocken, M.I.Ae.E.; Mrs. R. H. Stocken.

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G. M. Ure, Esq.

Dr. Ir. H. J. Van der Maas; Dr. A. H. Van Scherpenberg (Secretary, German Embassy); Mrs. Van Scherpenberg; Sir Alliott Verdon-Roe, Kt., O.B.E., F.R.Ae.S., M.I.Ae.E.; G. B. Vinycomb, Esq.; T. B. Vinycomb, Esq.; Mrs. T. B. Vinycomb; Miss B. Voyce; Air Vice-Marshal Sir Vyell Vyvyan, K.C.B., D.S.O.; Lady Vyell Vyvyan.

Flight Lieut. E. C. Wackett, A.F.R.Ae.S.; Mrs. E. C. Wackett; Sir Gilbert Walker, C.S.I., F.R.A.S., Sc.D., F.R.S., Ph.D., M.A.; Lady Walker; C. C. Walker, Esq., Assoc.M.Inst.C.E., F.R.Ae.S.; P. B. Walker, Esq., M.A., Ph.D., A.F.R.Ae.S; Captain C. E. Ward, A.R.Ae.S.I.; Mrs. C. E. Ward; Flight Lieut. Warnsborough; Dr. H. C. Watts, M.B.E., Assoc.M.Inst.C.E., F.R.Ae.S.; Mrs. H. C. Watts; Miss Weinstein; Air Commodore J. G. Weir, C.M.G., C.B.E., G.C.B., F.R.Ae.S.; Mrs. J. G. Weir; T. Wewege-Smith, Esq.; Mrs. T. Wewege-Smith; W. E. Wickham, Esq.; E. Wieser, Esq., B.Sc., D.I.C., A.F.R.Ae.S.; D. L. Hollis Williams, Esq., B.Sc., A.F.R.Ae.S.; Mrs. D. L. Hollis Williams; D. H. Williams, Esq., B.Sc., A.F.R.Ae.S.; Flight Lieut. T. M. Williams, M.C., D.F.C., R.A.F.; Wing Commander G. W. Williamson, O.B.E., M.C.; H. A. Wills, Esq.; Mrs. Lawrence Wingfield; C. G. H. Winter, Esq.; R. McKinnon Wood, Esq., O.B.E., M.A., Assoc.M.Inst.C.E., F.R.Ae.S.; Mrs. McKinnon Wood; Miss F. M. Wood.

Captain F. T. Young.

The PRESIDENT (Mr. C. R. Fairey, M.B.E., F.R.Ae.S.): This is the occasion of the 22nd Wilbur Wright Memorial Lecture when we meet under the wings of the first man-carrying aeroplane that ever achieved controlled flight, to do honour to the memory of the man, who in co-operation with his brother, Mr. Orville Wright, set up this the greatest milestone in the progress of aviation.

Before introducing the distinguished lecturer this evening it is my very pleasant duty to announce, after our custom, the awards made by the Council for the year 1933-34.

It is my very special pleasure to announce that the Amulree Committee have made the award of the first British Gold Medal for Aeronautics to Captain Geoffrey de Havilland. This new medal is awarded for an outstanding achievement leading to the advancement of aeronautical science, and I think you will agree that its award in this case is an extremely fitting one.

The medal was founded for this purpose at the instigation of Lord Amulree, then Secretary of State for Air, who honours us by his presence here to-night, and is awarded by a special committee of the Society which has been made as representative as possible.

To such an audience Captain Geoffrey de Havilland needs little recommendation from me. His name is one of the best, if not the best, known in British aeronautics. He built and flew his first aeroplane in 1910 and incidentally designed the engine himself. His fame as a designer of war planes is unrivalled, and since the War he has been the pillar of civil aviation in this country. His achievements as a pilot rank in the same class and only last year he won that most arduous race the King's Cup. It is a great pleasure to me to have the opportunity of presenting this, the first medal, which I am sure you will agree is very justly bestowed.

Next I have to announce the award of the Simms Gold Medal, given for the best paper of any year read before the Society on any science allied to aeronautics. This year the medal is awarded to Sir Gilbert Walker for his paper on "Cloud Formation." Sir Gilbert Walker has been Professor of Meteorology at the Imperial College of Science since 1924 and is a member of the International Commission for the Study of Motorless Flight. The paper was one of outstanding interest and I am very glad indeed that the medal has so distinguished a recipient.

The next award is that of the Wakefield Gold Medal, awarded for an invention tending to safety in flight, and here again I am sure you will agree that the recipient has been very well selected, since it is awarded to Senor J. de la Cierva, the inventor of the autogiro. You will recollect that he obtained the Silver

Medal of the Society in 1932, and the further advances made with his invention since then certainly justify this further award. We have, in fact, as yet to place Senor Cierva in history. So far, I believe, although over 1,000,000 miles have been flown on his machines, only one fatal accident has ever been recorded and that was due to an obvious and quite avoidable mistake on the part of the pilot. It may yet prove true that Senor Cierva has invented the safest form of travel.

Next comes the Taylor Gold Medal, and yet again awarded to a very distinguished personality. I have to announce that it has been awarded to Mr. A. Plesman, the Managing Director of K.L.M., for his paper on the Amsterdam-Batavia Weekly Service. Many of us present that night, who enjoyed Mr.

Wilbur Wright.

Plesman's paper and the subsequent debate, will I am sure applaud the award of this medal. I have no hesitation in describing this as one of the most valuable papers read before the Society.

Next we have to consider the Busk Memorial Prize, awarded for the best paper received by the Society on some subject of a technical nature in connection with aeroplanes or seaplanes, and this is awarded to Mr. A. V. Stephens for his paper on "Recent Research on Spinning." Mr. Stephens has been at the R.A.E. since 1930, where he has been concerned with the development and working of the interesting spinning tunnel and on full-scale work. We think no more suitable award could have been made for this than the present one.

Finally, the Pilcher Memorial Prize for the best paper by a student on heavier-than-air craft awarded to Mr. W. H. Lewis for a very excellent paper on "Duralumin as Applied to Aircraft Construction."

I now turn to the event of the evening, the reading of the 22nd Wilbur Wright Memorial Lecture which, as you know, is read alternately by a lecturer from abroad and from England. Previous lecturers have included most of the famous names in the science of aeronautics in the world, many of whom, I am glad to say, are present with us to-night.

This evening the lecturer is Professor B. Melvill Jones, who holds the Emile Mond Chair of Aeronautics at Cambridge, and his subject is " Stalling." There is not a more important subject and we could not have found a better qualified lecturer. We are very gratified that Professor Melvill Jones was able to accept the invitation and chose so interesting a subject.

It so happens that the more famous a lecturer is the less a chairman needs to say about him, in fact to give you a true sketch of Professor Melvill Jones' career and achievements I should take almost as much time as the lecture itself. Perhaps it is sufficient to tell you that as a pioneer he was with the Armstrong-Whitworth Company in 1913 and joined the Royal Aircraft Factory in 1914. He qualified as a pilot and served with No. 48 Squadron in France and subsequently in the Technical Department of the Air Ministry and retired with the rank of Lieutenant-Colonel in 1918. He was a Junior Fellow of Emmanuel and Director of Engineering Studies in 1919, and he has held the Emile Chair of Aeronautical Engineering at Cambridge since that date. He is now a Fellow of Emmanuel College and a Member of the Aeronautical Research Committee.

It is with the greatest pleasure that I introduce to you Professor Melvill Jones.

STALLING

BY

PROFESSOR B. MELVILL JONES,

A.F.C., M.A., F.R.AE.S.,

Francis Mond Professor of Aeronautical Engineering,

Cambridge University

This is the fifth occasion on which I have had the honour to address our Society and the third time I have chosen to discuss the same subject: " The stalling of aeroplanes." I should apologise for thus harping upon a single string were it not that no subject could be more appropriate to an address in memory of Wilbur Wright, and were it not that until the stall is thoroughly understood and its attendant dangers pushed out of the way, aviation will not be free to play the great *rôle* which it is undoubtedly destined to play in the civilisation of the world.

For my part, I believe that, but for the dangers inherent in the stall, the art of flying without power would have been mastered in very early times and handed on to us developed to a perfection greater than has yet been attained. There has always been the example of the birds to prove that flight is not impossible, and the simple materials necessary for the construction of gliders have been available from very early times. To construct and fly a glider *above* the stalling speed would surely have required no more imagination and skill than, say, to tame and control the wild horse; but every pioneer sooner or later had, all unprepared, to encounter the stall and, knowing what we now know about it, we can well understand that the probability of his surviving the first encounter was remote indeed.

Thirty years ago—" might as well try to fly "—was used as a synonym for attempting the impossible, and the reason for the attitude of mind reflected

in this phrase must, I think, be sought in racial memory of countless attempts, which began successfully but ended fatally on the first occasion when the stall was encountered at a fair height above the ground.

The Wrights began with a careful study of all previous records of attempted flight and this study suggested to them that some form of hitherto unsuspected trap might be responsible for the seemingly inevitable fatalities which had closed each attempt. They therefore decided never to leave the ground by more than a few feet until they had discovered what the trap could be, and it is, I think, the day on which this decision was made that more than any other marks the beginning of the modern era of flight. All honour to the Wrights, that by forethought they avoided the pitfall which had hitherto barred the way to progress and so survived to hand their knowledge on. Had they also fallen into the trap, it is possible that the mysterious deaths of a few more pioneers would have confirmed the universal view that attempted flight spelt suicide, and interest might have again lapsed for a long period.

What did the Wrights discover about the stall? Simply that at slow speeds either wing is liable to start a sudden downward and rearward movement, which, if unchecked, results in a spinning dive to earth. They countered this movement by interconnecting rudder and warp (the equivalent of aileron) so that either wing could be pushed upwards and forwards by a single movement of the controls. Though we do not now use their method of interconnecting controls, yet, after a vast amount of research, we still aim at achieving the same result: to force the wing tip upwards and forwards. These considerations, I think, justify my opening remark that the subject I have chosen is peculiarly appropriate to a lecture in memory of Wilbur Wright.

After the Wrights had found out enough about the stall to avoid being killed by it in their early experiments, no appreciable progress was made in the scientific study of the matter for at least fifteen years, during which time flying progressed from a miracle to an every-day occurrence. The reason was that the light petrol engine had made it easy to fly always well above the stalling speed and it was natural for pioneers, and after them the war pilots, to disregard a danger which could so easily be avoided. The steady succession of deaths from accidental stalling were, in those strenuous times, rightly attributed to pilot's error and the matter left there.

After the war, when attempts were being made to bring flying into every-day life and death by violence had ceased to be a normal event, it became clear that a phenomenon which was responsible for two-thirds of the fatal flying accidents, and which for ever lay in wait to claim a life as the price of a moment's inattention, merited at least careful scientific study. It was then that the Aeronautical Research Committee started upon a research campaign to unravel the causes of the strange behaviour of the stalled aeroplane; a campaign which has continued with varying degrees of urgency up to the present time, and seems likely to continue for some time to come.

From these and other researches we now know a great deal about the motions which follow a stall and about the causes which produce them. We know also how to avoid the worst of the dangers by relatively simple means. Suitably arranged slots in front of the outer parts of the wings, combined with a rudder which retains an adequate power when the aeroplane has stalled, will do this; so that in one sense the problem has been solved. The first urgency has passed and we can study the problem in that calm atmosphere beloved of the scientist and appropriate to the university or research establishment. In his inmost heart the scientist is always more interested in reasons than in results, and though urgent necessity may occasionally force him to exalt results above reasons, it is with a sigh of relief that he returns to his natural and legitimate frame of mind.

Sitting back, then, and surveying the problem from this more peaceful point of view, we find that it is by no means completely solved. We find unslotted aeroplanes varying from types which were so dangerous that they could not be put into service, to types upon which accident due to inadvertent stalling are very rare. Even amongst aeroplanes with slotted wings and obviously adequate rudders we find considerable differences of reputation between the different types. I think that those who know will agree that these differences cannot always be adequately explained, and so long as this has to be admitted the problem cannot be regarded as finally solved. It is with the experimental methods by which these differences in behaviour may possibly be explained that the major part of the lecture will deal, but first we must spend a few minutes considering the kinds of experiment which have given us our present knowledge of the details of the stall.

These experiments were of two kinds. Experiments on small models constrained to move in various simple ways provided data from which the free movements of the aeroplane could be calculated, and it is in the process of these calculations that we get to know the detailed causes of the motions and how they will be affected by modifications of the aeroplane. But we can never be sure that the stalling phenomena will occur on the model in exactly the same way as on the real aeroplane, and the calculations have necessarily to be based on drastic assumptions; moreover, the problem depends on pilot psychology and physiology as well as upon the aeroplane itself, so that for all these reasons it is necessary to obtain accurate records of the movements of the actual aeroplane, both when uncontrolled and when controlled by the pilot.

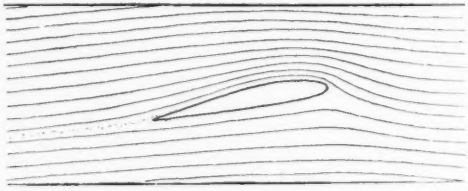
The first difficulty encountered was to find anyone who could fly a stalled aeroplane with reasonable steadiness. The now well understood art of stalled flying had to be learned before the behaviour of the stalled aeroplane could be studied. This initial difficulty and the subsequent difficult problem of designing and operating apparatus which could record three angular velocities simultaneously and correlate them with the movements of the three controls, were successfully overcome by the pilots and research staff of the Royal Aircraft Establishment.

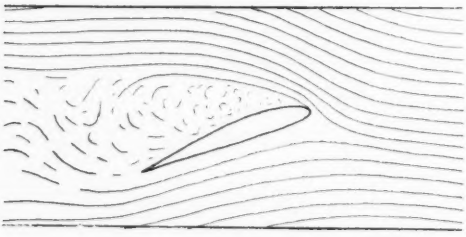
I have always had a great admiration for the pilots and observers of the R.A.E. who have carried through these and similar free flying experiments. Being Government servants their successes in a dangerous and difficult branch of research have at times been belittled and their failures magnified out of all proportion, and it must be a novel and amusing experience for those of them who survive to hear themselves praised in public. But it ought to be realised that the free flying experiment provides the essential cutting edge of the tool of aeronautical research, and that we have had at Farnborough for many years an organisation for free flight experiment which has done work of incalculable value to the development of aviation. A successful research enables problems which once seemed hopelessly complicated to be expressed so simply that we soon forget that they ever were problems. Thus the more successful a research the more difficult does it become for those who use the result to appreciate the labour which has been put into it. This perhaps is why the very people who live on the results of past researches are so often the most critical of the labour and effort which, in their time, is being expended to simplify the problems of the future.

But to return from this digression: calculation, based on wind tunnel experiment was singularly successful in explaining the causes of the peculiar behaviour of stalled aeroplanes. The spontaneous spiral dive which was the cause of all the trouble was shown to be exceedingly sensitive to yawing moments, and this was found to explain the complete failure of the ailerons to check it. As is now well known, it is the indirect effect of the yawing moments exerted by the ailerons which ultimately overpowers their direct effect in the spiral dive. The

knowledge that the motion was very sensitive to yawing moments also suggested that the rudder should have an important effect in checking the dive, and when this was realised it was soon found that the conventional rudder of those days, though adequate in unstalled flight, was insufficiently powerful for stalled flight. A general increase of rudder power then followed, with beneficial results, but again calculation, based on wind tunnel work, showed why rudder control alone was unsatisfactory.

The first completely successful control of the stall was developed at the R.A.E. by interconnecting a wing tip slot with the ailerons; an arrangement which gave exactly the effect aimed at by the Wrights when they interconnected aileron and rudder. The remainder of the story is well known to everyone. How the Handley Page automatic slot, which remains permanently open in stalled flight and closes automatically in unstalled flight, prevents the deadly spiral dive





FIGS. 1 AND 2.

Freehand sketches illustrating flow in the unstalled and the completely stalled states (see footnote on page 757).

from occurring, though it does not give much power of rapid control; and how the power of rapid control in the stalled state can be retained by the use of the "interceptor," which has substantially the same effect as interconnecting the slot with the aileron.

You will not have failed to notice how the progress of research has consisted of a re-discovery of the discoveries made by the Wrights in the beginning of things, but you will notice also that the later discoveries are now backed by a wealth of quantitative information which was necessarily unknown to the pioneers. We must extend to the Wrights the admiration due to pioneers, whilst realising that our present state of knowledge could not have been reached except as the result of laborious and elaborate quantitative researches.

Now, having briefly surveyed the history of our subject, we must ask ourselves why it is that these elaborate researches have not enabled us to predict with certainty the idiosyncrasies of different aeroplanes in the stall? To answer this question we must return to the beginning and consider the nature of the changes in the flow of air which are responsible for the stall.

Fig. 1 shows diagrammatically the flows past an aerofoil in normal flight and Fig. 2 shows the same thing in completely stalled flight.* The stall itself is the process by which the flow changes from the one to the other of these forms.

The details of the intermediate flows which can exist between these extreme forms may be extraordinarily complicated and they cannot yet be followed by mathematics, except perhaps in their earliest stages. To-night I shall not deal at all with the mathematical side of the problem, but shall discuss the various forms which the the changes can take and the effects which they have upon the forces acting upon the wings.

Many years ago—in 1912 to be precise—Professor Bairstow and I made the experiments which gave the curves of Fig. 3; these relate to a series of aerofoils

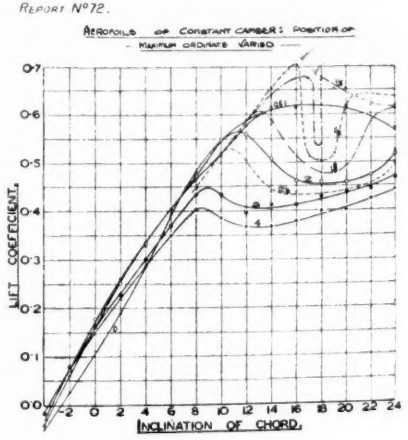


FIG. 3.

Typical curves of lift against incidence, from Report No. 72 of the British Advisory Committee for Aeronautics.

of constant thickness and camber but with the maximum thickness at various distances from the leading edge. We were working in the curious old return flow 4ft. wind tunnel of the N.P.L. which has now vanished from the world like prehistoric monsters of the Pleistocene age. I remember well the day when we first struck the precipices in curves marked $1\frac{1}{4}$ and $1\frac{1}{2}$; we both thought that the model had come adrift, and having in those days no windows to our wind tunnels we shut off the power and investigated; we had to repeat this process several times before we realised that we were observing an aerodynamic phenomenon. Many other experimenters have since produced similar families of curves, but these provide convenient examples of three typical ways in which aerofoils behave in the stall. Ever since we made those experiments in 1912 it has annoyed me to think that I could not imagine a fluid mechanism which could adequately explain all the features of the curves, so you can well imagine how pleased I was when, last autumn, some experiments which we were making in our wind tunnel at Cambridge showed up clearly the nature of the flow changes responsible for the main features of the curves, and provided the connecting

* These, and similar diagrams, are free-hand sketches in which the outlines of the turbulent regions are from actual observation, but the streamlines and the details of the turbulent motions are filled in by eye to make the figures more readily understandable. These details are not based on precise observation or calculation.

links between those in which lift changes progressively and those in which it changes suddenly.

The origin of these experiments was as follows. We have in Cambridge an organisation called the University Air Squadron, which is run by the Air Ministry with the primary object of teaching young men to fly, but in which, by the co-operation of the Director of Research, we are able to carry out experiments in actual flight upon aeroplanes specially provided for the purpose. In the autumn of 1932 we decided to use these facilities to study the airflow around an aeroplane in flight; and, in order to teach ourselves how to interpret the flow observations in terms of the forces acting on the different parts of the wings, we embarked upon a preliminary series of experiments in our very small wind tunnel, whose cross section is no more than 28 × 20 inches.

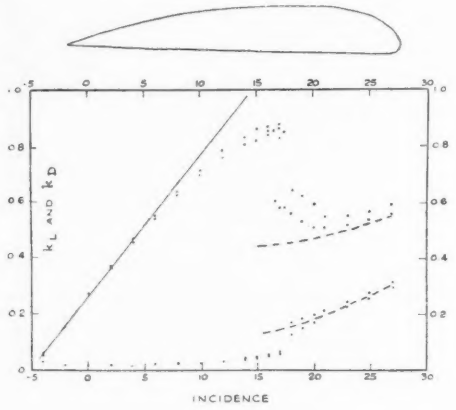


FIG. 4.

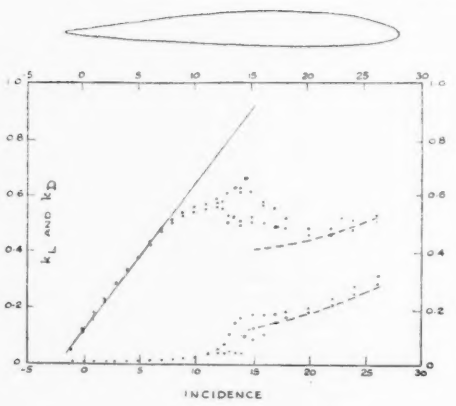


FIG. 5.

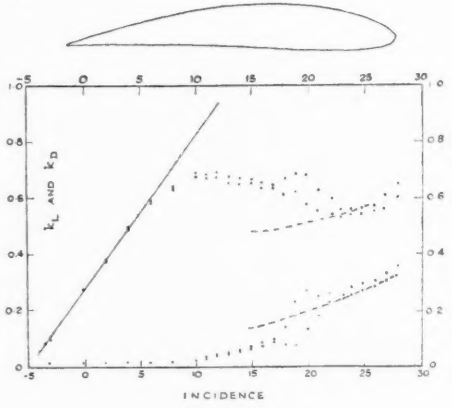


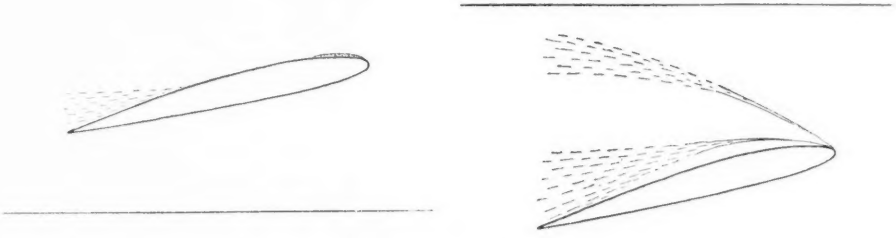
FIG. 6.

Lift and drag coefficients against incidence (degrees) for three wing profiles with approximately two-dimensional flow. The upper and lower points of each pair show the limits between which the forces were fluctuating.

In these experiments we measured the forces and pressures, etc., on a number of model wings and tried to correlate them with observations of flow obtained by watching a minute silk filament glued to the point of a needle, which could be moved about in the field of flow. Our model wings extended right across our tunnel, so as to eliminate the complications arising from the flow round the ends, and our method of measuring forces was unusual in that we removed most of the damping from the balances and concentrated upon observing the greatest and least forces at any incidence, rather than upon the mean of any fluctuations which might be occurring. It was the adoption of this unusual technique which enabled us to obtain the results I am going to describe, results which, I think, show up some aspects of the stall in a new light.

We found that the aerofoils could be divided into three main groups according to the way in which lift and drag varied while the stall was occurring.

Fig. 4 shows one typical form of this variation; two observations of lift and two of drag are here given at each incidence, to show the limits of the fluctuations of the forces at those incidences; a wide spacing between the upper and lower points of each pair indicates that the force was varying considerably although the incidence was held at a constant value. The comparatively steady



FIGS. 7 AND 8.

forces at the lower incidences, where the points are close together, are typical of the unstalled state; if the flow were to continue in this state at the higher incidences the lift points would continue to lie nearly on a straight line and the drag points would keep very low, but, as you see, the lift curve bends and the drag increases slightly at incidences above 7°, whilst at 17° lift falls and drag rises suddenly towards the broken lines, which represent roughly the values to be expected in the completely stalled state.

Another typical way in which the lift and drag can vary during the stall is illustrated in Fig. 5, where no definite discontinuity is shown but, instead, a sudden considerable widening of the distance between the curves formed by the observation points. This indicates severe fluctuations which persist over an incidence range of some 5° or 6°. The onset of these fluctuations coincides with the passage of the incidence of maximum mean lift.

Fig. 6 illustrates the third typical mode of variation and lift and drag. Here the curves are similar to those of the previous group, except that the sudden increase in the fluctuations does not occur until an incidence several degrees greater than that of the maximum lift. The passage of the maximum lift itself occurs without any marked fluctuations or discontinuities.

Now we must study the flow changes which are responsible for these different typical force changes. We have to consider in some detail the way in which the flow changes from the form illustrated in Fig. 1 to that in Fig. 2.

With all the aerofoils tested the first noticeable sign of the approaching stall is the formation of a region roughly sketched in Fig. 7, in which " total

head " falls below the constant value which it would have in unstalled flow, but in which there is no definite separation of the stream from the aerofoils' surface. In this region the silk thread turbulence detector shows slight tremors, but not the violent turbulence associated with true separation. Apparently the formation of this region of partially retarded flow is responsible for the bending of the lift curve and for the slight rise of drag which I have already mentioned as indicating the approach of the stall with all the aerofoils which we have examined.

During this stage, which precedes the true stall, we have found that the air-stream may separate from the leading edge, and then quickly rejoin the surface again to form, as in Fig. 7, a kind of shallow bubble in which the flow is turbulent and the pressure uniform, but very low. This phenomenon has but little influence on the over-all forces which act on the aerofoil, but the possibility of its occurrence gives a clear warning that theoretical calculations of the critical condition which leads to separation of the stream from the aerofoil cannot always be trusted to give the incidence of maximum lift, or indeed to be in any obvious way related to the variations of total reaction on the whole aerofoil.

Neither of the phenomena which we have been discussing is of primary importance in the main problem of the control of stalled aeroplanes; interesting as they are from the theoretical point of view they must, from a practical point of view, be regarded merely as giving warning that the true stall is approaching. It is in the next stage that the flow changes occur which are responsible for the peculiar dangers of stalled flight and it is in accordance with what happens in this next stage that the aerofoils fall into one or another of the three groups previously considered.

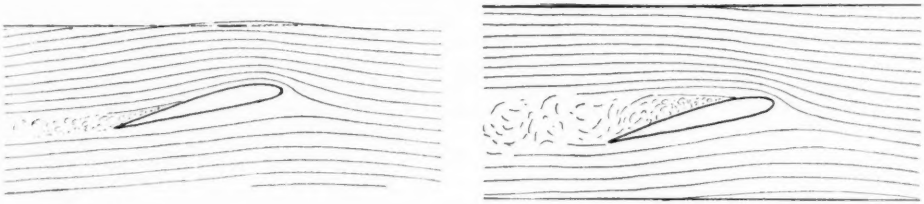
Let us consider these three different behaviours one by one. Consider first the aerofoil which showed definite and large discontinuities in the lift and drag curves (Fig. 4). With this aerofoil the first definite separation of the stream from the upper surface occurred from the leading edge suddenly and completely, so that the boundary of the main stream passed well clear of the remainder of the aerofoil and a permanent region of " dead air " of uniform low pressure was formed over the whole upper surface, as in Fig. 2. This sudden change coincides with the discontinuity in the force curves of Fig. 4 and, as is usual in these circumstances, there is a small incidence range within which either the stalled or the unstalled forms of the flow can be maintained indefinitely, so that the curves overlap, as shown.

This sudden and permanent change of flow occurs only when there is a large difference between the values of the lift before and after the critical change; if this difference is not so large, the first complete separation of the stream from the leading edge is followed by a remarkable phenomenon, the reason for which I cannot yet explain, but whose existence seems to be beyond doubt.

It appears that the boundary of the main stream may alternate between two fairly distinct forms which I have roughly sketched in Fig. 8; one of these forms represents the completely stalled state already discussed, in which the boundary passes well away from the trailing edge and is clearly defined towards the front, but less clearly towards the rear. In the other form the boundary is also clearly defined towards the front, but remains within three or four inches (on the full scale) from the surface, for about half the width of the aerofoil and then becomes diffuse and hard to define, as roughly indicated in the figure. The alternations of the flow between these two forms are very rapid when thought of in terms of measurement of forces on a small model, but they are surprisingly slow in terms of the distance travelled by the aerofoil through the air. Either kind of flow can and generally does persist while the aerofoil travels through a distance many times greater than the length of its chord. It is these alternations which are responsible for the violent fluctuations indicated by the sudden widening of the space between the curves formed by the points of Figs. 5 and 6.

Disregarding the shallow " bubble " of turbulence which we have seen may form behind the leading edge at relatively low incidences, we find that the first clear sign of the separation of flow from the leading edge always coincides either with a complete discontinuity in the force curves or with the onset of violent fluctuations. This, however, does not necessarily happen at the incidence of maximum lift; with some aerofoils, particularly when they are thick and have the maximum camber far back from the leading edge, the first definite separation of the flow occurs near the trailing edge and a dead region then appears in the form illustrated in Fig. 9. This dead region expands gradually with increasing incidence up to the form roughly sketched in Fig. 10, and during this growth lift falls gradually as in Fig. 6 without serious fluctuations or discontinuities. Eventually, however, even in these circumstances, the flow separates suddenly from the leading edge and the characteristic fluctuations appear, but now, of course, at an incidence considerably greater than that of maximum lift.

Many of you will remember that Professor Prandtl showed us, in his beautiful Wilbur Wright lecture some years ago, how the separation of flow from a surface is caused by the action of a pressure gradient upon the air in the boundary layer. From our experiments it now appears that as the incidence of a wing of moderate thickness increases there are two points in the boundary layer where the conditions tend towards separation of the flow from the surface, one of these is near the leading edge and the other near the trailing edge. What actually



FIGS. 9 AND 10.
Freehand sketches illustrating rear stalling.

happens depends upon a kind of race between the development of these two conditions. If what we may call front stall wins the race, discontinuities or violent fluctuations mark the attainment of maximum lift, whereas, if rear stall wins, all such violent phenomena are postponed to incidences considerably higher than that of maximum lift.

To complete the picture you must realise that the occurrence of rear stalling modifies the main flow so as to reduce the danger of front stalling and hence when rear stall wins the race, even by a small margin, all violent fluctuations or discontinuities may be postponed until many degrees beyond the incidence of maximum lift. It does not take much imagination to see how this state of affairs may account for the peculiar sensitivity of some wings to small changes of shape and to other variables.

Consider now the light which these ideas throw upon the curves of Fig. 3. In the curves numbered 4 to $1\frac{3}{4}$ we may suppose that front stall won the race and was followed by an incidence range in which the forces fluctuated considerably, but the mean values, which alone were recorded, showed no obvious signs of discontinuity. It must be remembered that in these, as in almost all published wind tunnel experiments, the balances were heavily damped and the observers concentrated upon obtaining good mean values rather than upon the measurement of fluctuations.

In the curves marked $1\frac{1}{2}$ and $1\frac{1}{4}$ we may suppose that front stall was so long delayed that when it occurred there was no intermittent return to the high lift form, and therefore the sudden fall in lift which always follows the front stall was no longer disguised by fluctuations.

The curve marked 0 and 1 (which is in reality two nearly coincident curves for two different aerofoils) must be regarded as the result of rear separation occurring first and postponing front separation to an incidence greater than the limit of the experiment.

The recovery at high incidences of the lift in curves 2 to $1\frac{1}{4}$ requires explanation. I regard it as due to rear stall developing, at the larger incidences, sufficiently to relieve the strain on the boundary layer near the leading edge and so to prevent the occurrence of front stall. It must be remembered that each experimental point on these curves was obtained after the aerofoil had been at a fixed incidence for a considerable time, so that if, at any time during this period, the flow occurred without front separation, then rear separation might develop and prevent return to the more completely stalled state.

In passing it is worth mentioning that a general study of the published records of experiments on wings suggests that while front separation is postponed by increasing Reynolds number, rear separation may be encouraged. This may be found to explain many of the complicated effects of change of scale which have hitherto been so puzzling. I regret that time will not allow me to go further into this interesting side of the subject; we must pass on at once to the consideration of how these ideas react upon the problems of stalled flight.

From what I have said it should be clear that the forces acting locally at any one part of the wings may change very suddenly as the incidence changes during a manœuvre, and a little consideration will show that these sudden changes may not be clearly revealed in curves such as are usually available, which show mean values of the lift and drag, each measured while the incidence is maintained approximately constant. Several distinct factors combine to disguise the sudden changes, both in model and free flight experiments. It is, for instance, well known that the stall does not occur simultaneously at different positions along the span of the wings, and in the free flight experiment it is impossible to hold incidence absolutely constant during the long period—one minute or more—necessary for an observation of lift and drag by the methods usually employed. It now appears that to these factors we have to add the factor that the flow may alternate through wide limits, even when the incidence is maintained constant.

In manœuvres of an aeroplane in flight, however, sudden changes of the forces on parts of the wings may have very disconcerting effects, and the point which I want to emphasise in this lecture is that it is these sudden and local changes which are responsible both for the principal remaining dangers of the stall and for the difficulties which we experience in predicting behaviour from calculations based on model experiments of conventional type.

It is, I think, clear that no sudden changes such as these should be allowed to occur on any part of the wings of an aeroplane in conditions which may be reached during any reasonable manœuvre near the ground. No machine which has to be delicately controlled should change its behaviour suddenly without warning. Imagine yourself driving a car on which the steering wheel when moved beyond a certain angle suddenly opens the throttle. Obviously, it should be our aim to eliminate these sudden changes altogether or postpone them to incidences which cannot be reached in ordinary manœuvres, and since we cannot hope to locate them by studying curves of lift and drag obtained in the conventional way, we must find other means of doing so. This is very easily done, provided that we can find some simple means of observing in flight the incidence at which the flow first separates from the leading edge, for, so far as our experiments go, it is only when the flow separates from the leading

edge that serious sudden changes occur. This brings me naturally to a brief description of the experiments which we are now making at Cambridge upon aeroplanes in flight.

In these experiments we study the flow by watching, or photographing with a small cinematograph, the movements of little tufts of wool fastened to the fabric of the wings, and to very light posts temporarily erected upon their upper surface. These posts and their bracing wires are attached to the wing merely by small fabric patches doped on to the surface and are so light that even if they carry away they can do no serious damage. They are very easily erected and removed.

Figs. 11 and 12 show the aeroplane equipped for observation. The posts are situated at the trailing edge and at one-third of the way back from the leading edge, so that they allow two points to be fixed on the boundary of the stream when it separates from the surface.

In unstalled flight these tufts remain practically still, pointing backwards as in Fig. 13, which is an enlargement from one exposure of a cinematograph record.

When the wing is completely stalled the tufts, as in Fig. 14, are violently agitated for a certain distance from the surface, but beyond this distance they stand out steadily in the air stream. The dividing line, of course, marks the boundary between the main stream and the dead air.

There are many variations in the behaviour of the tufts as, for example, when all those in a large region point more or less steadily forward (see Fig. 15) or when they do what we call buzzing, that is, vibrate rapidly while still pointing generally down stream (see Fig. 16), but at present we are concentrating upon broad features only.

The wings of our aeroplane have a section for which the flow separates first from the leading edge and then fluctuates between the two forms sketched in Fig. 8. This fluctuation is clearly shown in Fig. 17, which gives a record of the variations of the height reached by the turbulent region above the wing on three observation posts, situated at one-third of the chord behind the leading edge and spaced at intervals along the span, on the inner part of the wing, clear of the slot and of the wake of the airscrew, which was stopped. These records were obtained by examining photographs taken at a rate of 14 to the second, but small fluctuations of less than half a second period have been eliminated from the curves for greater clearness. The incidence at which these flow variations begin coincides exactly with the incidence at which the pilot begins to notice those erratic plunging movements which everyone with experience knows as characteristic of the stall. On our aeroplane, however, these movements were not very severe, because the outer parts of the wings were maintained in the unstalled state by means of slots.

Fig. 18 shows curves of lift and drag for our aeroplane obtained by the conventional methods of measuring these forces in flight. Notice that though the lift curve changes direction rather abruptly at 16° there is no indication of any sudden change in the forces themselves. The reason for this I have already explained. When, however, this aeroplane is stalled in a manœuvre in which incidence changes progressively, the change of flow over the unslotted parts of the wings, from the unstalled to the fully stalled state, may occur very suddenly and permanently so that the full effects of a discontinuous force change may be felt. We met this phenomenon of sudden stalling on the aeroplane in question when we were attempting to discover the cause of a very disconcerting sudden change of behaviour of the aeroplane in steep turns, begun at some 40 per cent. above the stalling speed in straight flight. We found then that the sudden flow change occurred at exactly the same instant as the change of behaviour and that its effects were greatly aggravated by sympathetic stall of the tail, caused no doubt by the change of the down wash from the wings. This sudden change of behaviour, due to stalling of the inner part of the wings and the tail, is not nearly

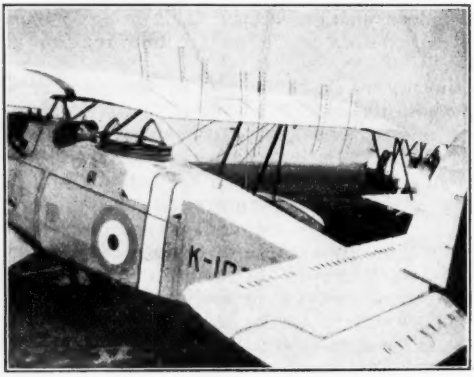


FIG. 11.

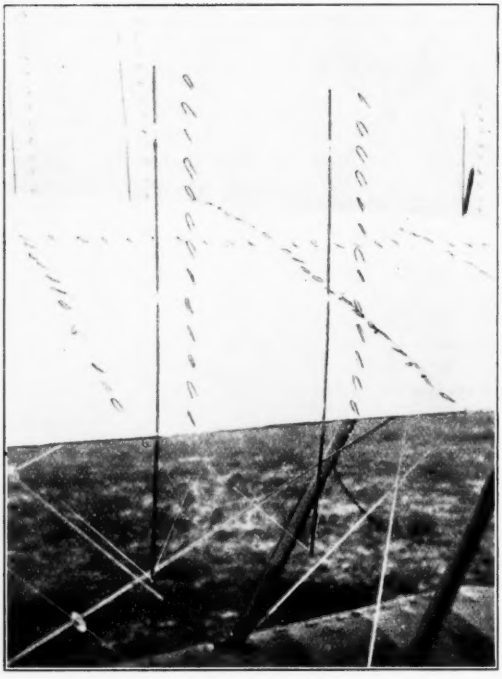


FIG. 12.

Aeroplane equipped with wool-tufts for observation of airflow in flight.

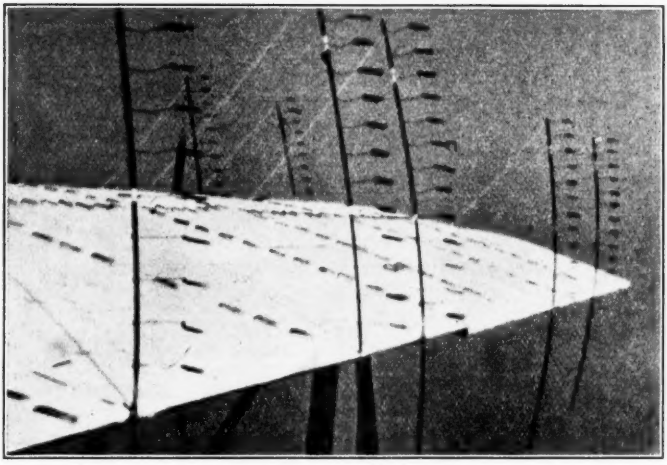


FIG. 13.

Unstalled flight.

Wool-tufts point steadily backwards. Forward posts are one-third of the chord behind the leading edge.

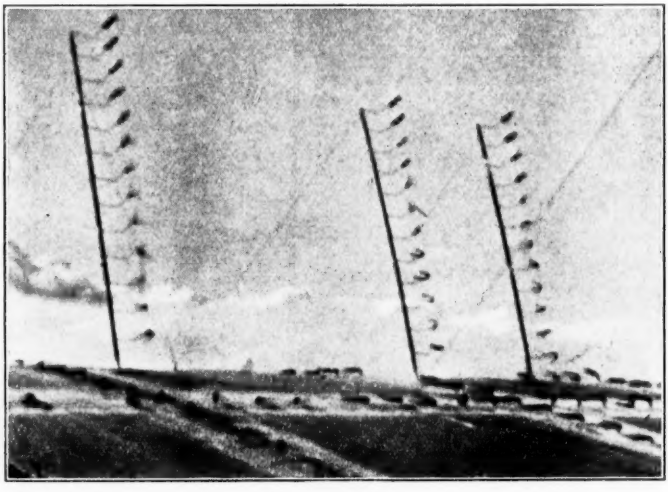


FIG. 14.

Stalled flight.

Wool-tufts on wing surface and on lower parts of posts show severe turbulence; upper three tufts on each post show streamline flow.

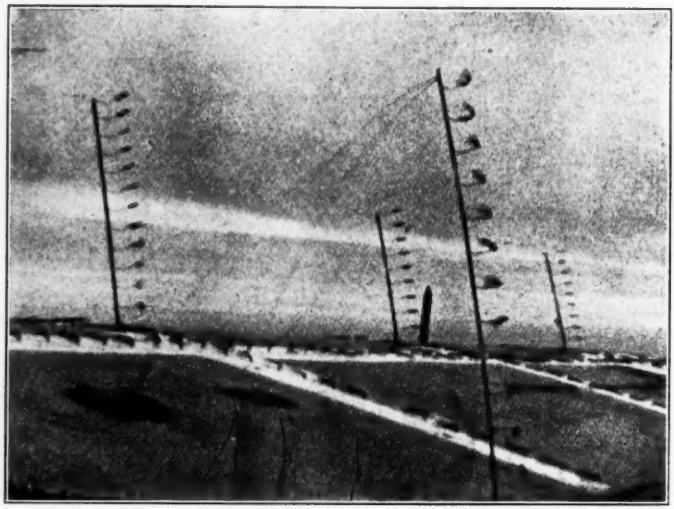


FIG. 15.
Stalled flight.
Wool-tufts show large regions of reversed flow.

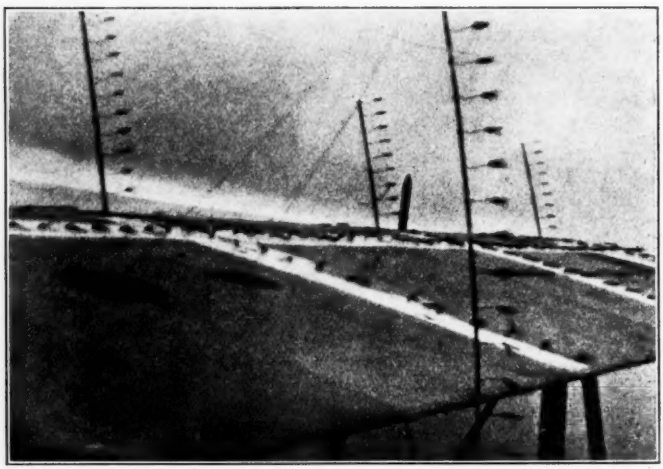


FIG. 16.
Intermediate state in which wool-tufts on surface and at bottom of front post show severe turbulence, but tufts on rear post show slight turbulence superimposed on general rearward flow.

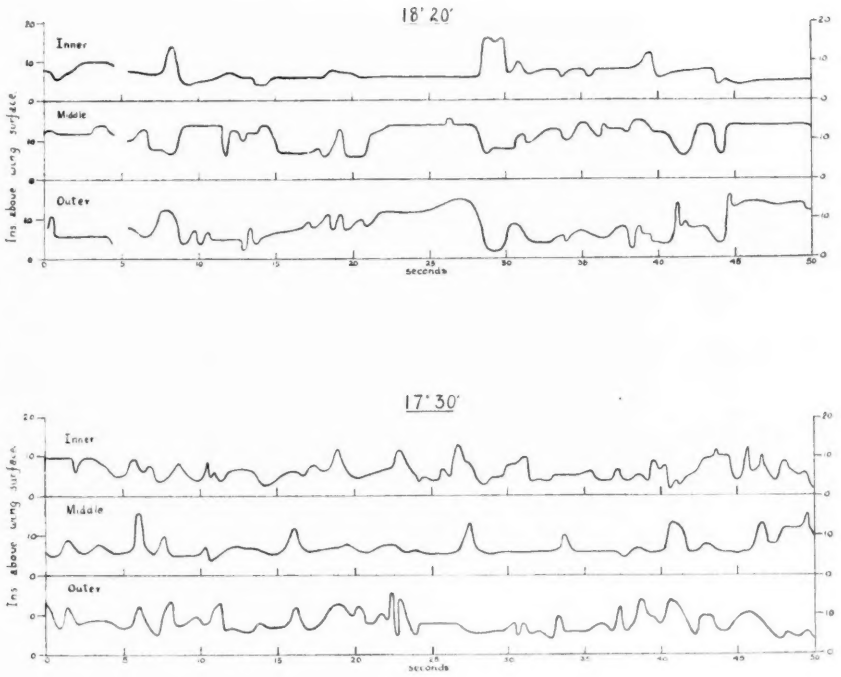


FIG. 17.

Variations of the depth of the "dead air" observed on posts situated one-third of the chord behind the leading edge, with lateral distance between inner and middle posts 28 *inches and between middle and outer posts* 14 *inches.*

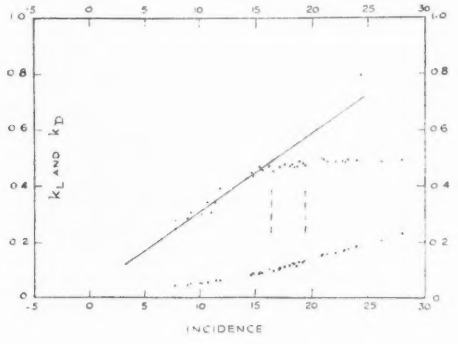


FIG. 18.

Full-scale measurements of lift and drag by conventional methods requiring more than a minute for each observation. The broken vertical lines define the incidence range in which the flow fluctuated as in Fig. 17.

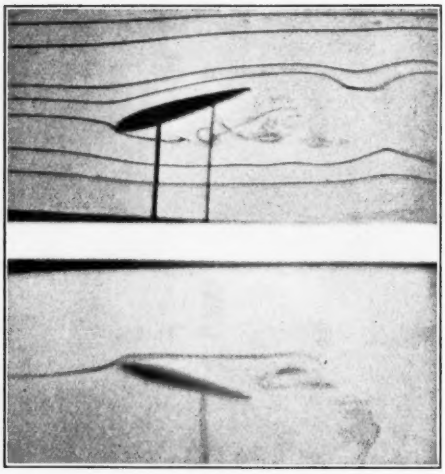


FIG. 19A.

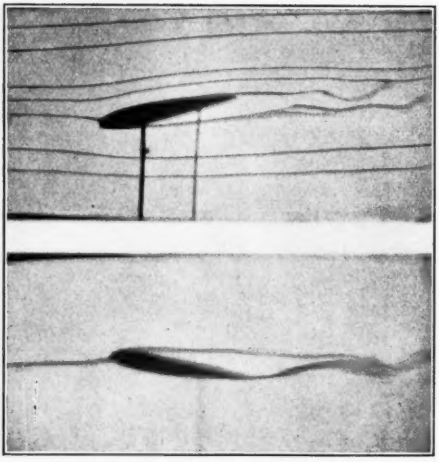


FIG. 19B.

Specimen views of the flow shown in the cinematograph. Fig. 19*a shows separation from the leading edge and* 19*b separation from a point some distance behind the leading edge. Above, water-flow; below, air-flow.*

so dangerous as the deadly spiral turn which may follow a stall on an unslotted aeroplane, but we now believe that it is responsible for the greater part of the few remaining accidents which still occur from stalling on slotted aeroplanes when they are steeply turned near the ground.

Let me try to summarise the position as I now see it. The research campaigns upon the stall, which began with the Wrights and have continued to the present day, have clearly shown the nature and causes of the movements of stalled aeroplanes and have indicated simple ways of overcoming the dangers, but they have not been markedly successful in explaining the causes of the minor differences between different types. In my own view one reason for this is to be found in the sudden flow changes which occur on some parts at least of the wings, in some stages of the stalls, and it has been one purpose of my lecture to show why the presence of these sudden changes is not in general revealed by the methods of experimenting which have been commonly employed in the past.

It seems that the older methods will need to be supplemented by new methods of experiment which will enable sudden local changes of force and flow to be detected. On the model scale, this calls for quick acting balances which record changes of lift and drag whilst incidence is progressively changing, and it will clearly be advisable to use some means of studying flow to supplement force measurements.

On the full scale it seems that the examination of the flow by some simple methods which can be easily applied in flight will be necessary for investigations of the causes of unsatisfactory behaviour at low speeds. By such means we should in time learn to recognise the forms of wing which are liable to sudden flow changes in any of their parts and either cease to use them or use only those on which the trouble is postponed to incidences greater than need be employed in ordinary manœuvres.

I fear that perhaps I have broken with tradition in using the Wilbur Wright lecture to discuss experiments which are still in an incomplete form, and to put forward ideas of somewhat tentative character. The reason is that I have been asked to give the lecture at a time when I am intensely interested in the matters with which I have dealt, and I have always held that the first essential in a lecture is that the lecturer must be interested in his subject.

I am well aware that in lecturing on experimental results so recently obtained I am in grave danger of over-emphasising aspects of the matter which are uppermost in my mind. If I have inadvertently given the impression that I think our experiments have virtually solved the stalling problem, I must emphatically correct that impression. What I think our experiments do show is that for further substantial progress it will be necessary to make more use than hitherto of experimental methods which have not commonly been used in the past. What such experimental methods will reveal, when applied more widely than to the very few wing forms which we have yet examined, remains, of course, to be discovered. I do, however, maintain that until we know when and how the stall occurs on each part of the wings in flight we shall not reach any clear understanding of the behaviour of aeroplanes at low speeds.

The lecture was illustrated by a film which showed the development of the stall upon small aerofoils in streams of water and air, and the movements of wool tufts in various stages of the stall of an aeroplane in flight. The first part of the film was obtained by photographing the shadows thrown upon a screen by Mr. W. S. Farren's projecting apparatus, which enables the movements of fluids to be displayed on a large scale for lecture purposes. Fig. 19 shows some typical flows which occurred in the first part of this film. The details

of the flow can be more clearly seen in the water pictures, but the air pictures were included to make it clear that in this connection there is no essential difference between the behaviour of the two fluids. The Reynolds numbers of the flows shown in these figures were so small that the flows cannot be assumed to be the same as those which would occur with the same sections on a larger scale, but the figures illustrate clearly the difference between stalling from the leading edge and from points some distance behind the leading edge.

A vote of thanks was proposed by Lieut.-Colonel Moore-Brabazon and carried with acclamation.

THE AUTOGYRO ROTOR AS A SAIL

BY

LIEUT.-COLONEL J. T. C. MOORE-BRABAZON, F.R.AE.S., M.C., M.P.

The idea of navigating a certain type of sailing boat of mine by an autogyro instead of an ordinary sail has long been a desire of mine, in that I always have considered sailors to be very out of date as to rigs.

In conversation with J. Weir this question arose, whereupon he said that he had within his organisation of the Autogyro Company an engineer named O. Reder who had the same desire. We, therefore, got in touch and although the time was very short got out a rig and installed it upon a very small one-design class, well-known in the Solent, namely, the Redwing. These boats are about one ton, and the rules governing their racing are that the hulls are standard and that any rig can be used, but that the sail area must not exceed 200 sq. ft.

FIG. 1.
Riding on moorings with rotor tied up.

To those who are acquainted with yachting, and Solent yachting in particular, the Redwing will appear as being one of the most difficult of boats to adopt to any new rig, in that the mast has to be stepped rather farther forward than in an ordinary boat to get the balance right, and it is a boat where the very latest forms of gadgets and devices are adopted, so the sailing is extremely good and the efficiency of the rig extremely high. To give an impression of the standard of the rig of this class let me say that the mast, the sails and all rigging complete in a first class Redwing weigh only 45 to 50lbs. and we were set the problem of trying to instal an autogyro to compete with this and not to so overload the boat as to make her excessively tender.

Mr. Reder got out a design which redounds to his credit, in that nothing at all actually went wrong or broke upon the sea, and I took the craft out in some pretty stiff winds. We installed a duralumin mast of two sections. It was stepped into the keel in a ball bearing and it traversed the deck also in a ball

bearing. It was 10ft high and carried a rotor weighing some 45lbs. of 18ft. diameter, the blades being 1ft. 6in. deep. The rotor plane was inclined to the mast 8° in order to clear it. The rotor was set back eight inches from the mast in order to get a slight pull on the boom—had it not been for this the boom would have had to have been pushed out instead of going out of itself. The boom naturally was rigid with the mast and the boat was sailed as if the plane of the rotor was a sail. The rotor had no angle on it at all as it had to rotate in the same direction with the wind coming from either side. It was, I think, the only sailing boat existing in which there were carried no ropes at all. We did, as a matter of fact, later have a rope to the end of the boom, but even that could have been dispensed with.

Our first trials were exceedingly interesting and precarious as no data on the behaviour of such craft or such a rotor was existent. It must be remembered that with the rotor clearing the deck only by a foot, and revving up to 250 revs., it is a dangerous thing in a sea, and any mistake of the crew might lead to very serious disaster.

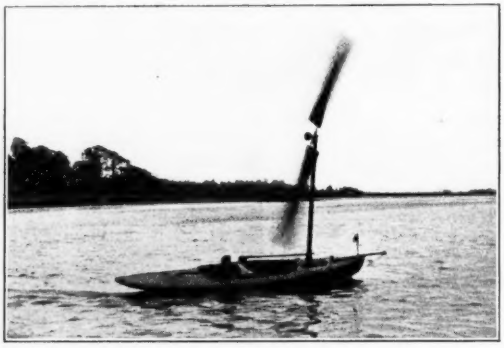


FIG. 2.
On a wind.

In a fairly strong wind of about 30 m.p.h. we made our first sally on the Hamble river. On giving the rotor a push she responded and proceeded to speed up, whereupon a very ugly phenomenon occurred as the series of buffets given to the top advancing blades of the rotor coincided with the natural harmonic of the mast. We thought at the moment that disaster was upon us, but the moment the critical speed was over the rotor settled down quite quietly and nicely and the mast seemed quite happy. It will be appreciated that it was impossible to stay the mast and that the whole of the driving force and thrust came from the top of the mast, giving a sheer on the deck. However, we had allowed for this and the boat did not seem to mind heeling quite naturally.

The general sailing of the boat was an interesting and difficult problem. The most interesting point of sailing was " on a wind " and here a new technique was required, as it will be appreciated that the angle that a boom in an ordinary sailing boat subtends to a wind is not the angle which the sail is making to the wind as the sail pays off so very much the higher you look at it until actually the top is but a flag. In our case the angle of the boom to the boat was the angle of the rotor and naturally was somewhat coarser than that of an ordinary boom. There was the secondary consideration that the speed of the rotor had to be maintained and this was greatest when squarish to the wind rather than at an angle to the wind. It will be seen, therefore, that the two points one

was striving for were rotor speed and sufficient angle to drive the boat, and at first these two were difficult to get going efficiently and smoothly. " Putting about " involved also the greatest technique, quite a different procedure, as the moment the boat shot up into the wind the rotor speed would fall, and in starting on the other tack, just when you wanted the maximum power and a coarse angle on the rotor, the rotor speed had gone down and you were tempted to pull the boom in to make the rotor spin at a time when from the point of view of the propulsion of the boat drive alone was wanted. We did, however, get the technique of this fairly satisfactorily, but the changing of the plane of rotation of the rotor certainly set up some alarming vibrations and jars, but after a time we got used to this and did not become so alarmed as we were at first, in fact we became quite callous to the astonishing whips arising. In this connection it is interesting to note that " jybing " was not more difficult than " putting about," as there was no surface like a sail to fill with a bang, and I would as soon " jybe " in the boat as " put about." On a " reach " the rotor spun at a most satisfactory speed and in a wind of, say, 20 miles per hour the progress made was quite astonishing. In " reaching " there was a danger in a short

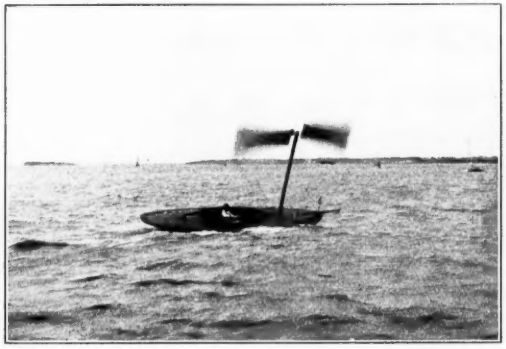


FIG. 3.
Reaching.

sea of the rotor blade touching the sea which would have led to disaster, and one always had that fear in mind, causing us often to have to luff up to avoid it. We had also fitted on the rotor an internal expanding brake, operated from the cockpit by a long bowden wire and lever. This delayed the speed of the rotor considerably when coming up to moorings and had a certain effect when the rotor was inclined to go too fast, but was not so powerful as to be able ever actually to stop it when being driven by a wind. In this connection I hope the difficulty of getting up to one's moorings will be appreciated by sailors as the crew had to keep their heads down if they wanted to avoid having them cut off, the rotor had to be stopped by the brake and the mooring picked up aft instead of forward. Although this is not a very seamanlike practice, it did not matter with us as there was no sail, once the rotor had stopped, to fill and introduce sailing again.

The general behaviour of the boat, in that it had only 35 sq. ft. of surface against the 200 allowed by other craft, was interesting. In light winds up to 7 m.p.h. I do not think the boat could compete against the ordinary marconi-rigged Redwing, as on a light wind the rotor first of all did not go fast enough, and in light puffy air, after the wind had dropped, the inertia of rotation stored up in the rotor did not give one much drive. On the arrival of a new puff the energy

of the wind had to be used entirely to get speed on the rotor. There were, therefore, unpleasant delays. If, however, the wind was over 15 m.p.h. and fairly constant, and the sea not too short and high, then the performance was, I consider, very remarkable. I never actually raced against other boats for reasons I will explain later, but experienced yachtsmen expressed the opinion that they had never seen a boat go so near the wind, and under certain conditions, after a great deal of experience of sailing small boats, I think that was the case.

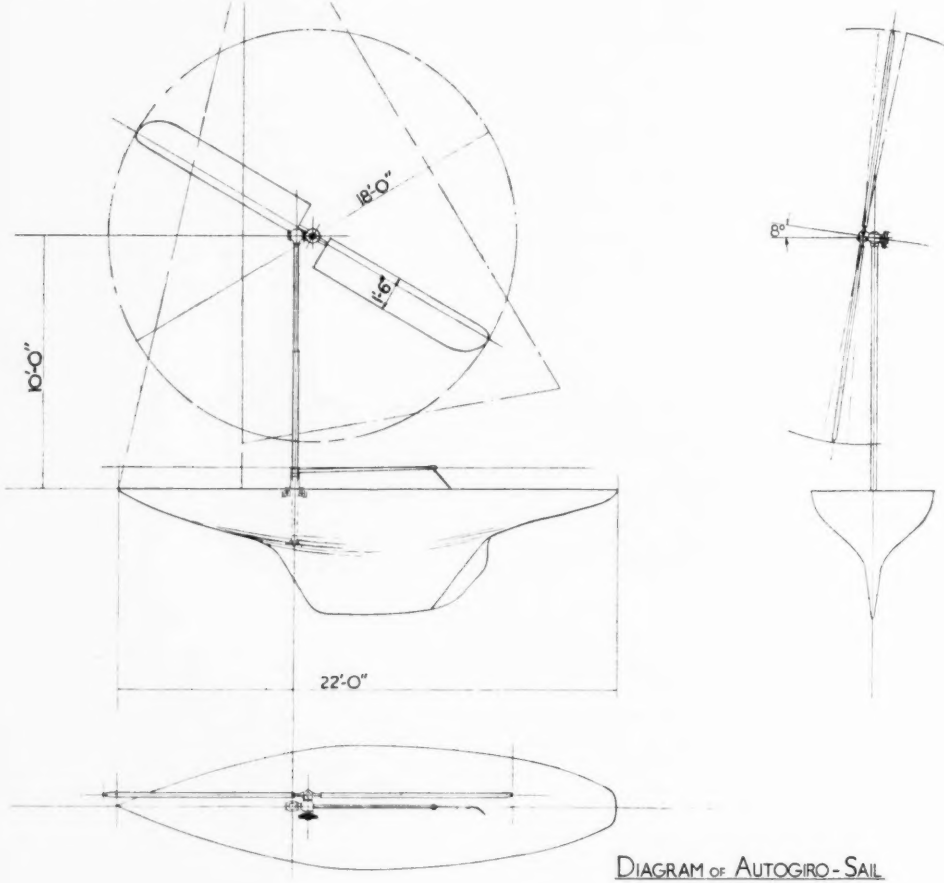


DIAGRAM OF AUTOGIRO-SAIL
O. REDER 2·6·34

It was my desire to race in the Redwing class during Cowes week, but so familiar did we get with the craft, and so self-confident were we, that we suffered one of the most childish of accidents which completely stopped further experiments. When on our moorings one day, in trying to get off instead of being towed off, we started up the rotor before we had got way on, we could not stop it and before we could do anything we drifted on to a dinghy with the most disastrous results to ourselves and the dinghy. This ended the experiment which was extremely novel and extremely interesting.

I have in my time fitted many new rigs to boats, as I like to approach the problem of harnessing the wind from an aeronautical point of view rather than that of the old-fashioned sailor, but many of one's best laid schemes go overboard in a blow. In this particular rig, however, providing one can avoid the rotor striking the water, I believe a smart blow would show satisfactory results. Everyone thought that the boat was motor-propelled, due to the fact that the rotor going up to hit the wind in its revolutions made a slight puffing noise which gave one the impression that there was an exhaust somewhere about. It was, however, satisfactory in view of my experiences not to be told, as I have often been told, that a rig exactly similar had been tried thirty years ago!

I do not consider the general adoption of a rotor instead of a sail a possibility as it is dangerous and impracticable, but racing craft and cruising craft are two very different things, and I believe in the autogyro there is a germ for a better way of getting efficiency out of a wind in a boat than in any other device so far tried, that is always under certain conditions, and although I have been beaten this year I intend to have another try later on.

AIR MINISTRY

RÉSUMÉ OF COMMERCIAL INFORMATION*

SERIES 5, No. 9, FEBRUARY-MAY, 1934

Compiled by the Directorate of Civil Aviation (C.A.3), Air Ministry, Kingsway, London, W.C.2

Note.—All currency conversions have been carried out at " par " rates.

Australia

Queensland and Northern Territory Aerial Services, Ltd.—Operations Statistics for 1933

	Passengers (by stages).	Taxi passengers.	Freight (lb.).	Miles flown.
January	255	8	2,870	17,032
February	254	24	2,640½	16,413
March	289	15	3,750	17,768
April	167	16	4,449	25,120
May	234	18	5,978	20,281
June	176	6	3,951	15,023
July	248	10	3,565	17,342
August	333	7	4,321	16,563
September	262	23	3,933	21,727
October	264	8	3,666	16,343
November	231	18	3,224	16,964
December	364	32	2,427	18,272
	3,077	185	44,780½ (20,312 Kg.)	218,848 (352,200 Km.)

Routes operated:—Brisbane—Camooweal; Cloncurry—Normanton; Daly Waters—Birdum Creek.—(Extracted from *Quantas Gazettes* for 1933.)

Canada

Canadian Airways, Ltd.—Operating Statistics 1931-1933

Distance Flown—

	1931. Miles.	1932. Miles.	1933. Miles.
Productive—Mail Lines ...	1,224,440	329,693	203,533
Other Lines	422,200	794,264	863,681
Total	1,646,639	1,123,958	1,067,214

* Abridged and Abstracted.

	1931.	1932.	1933.
	Miles.	Miles.	Miles.
Total—Mail Lines ...	1,336,107	371,310	210,666
Other Lines	496,687	922,897	954,769
Total	1,832,794	1,294,207	1,165,435
Hours Flown—			
Productive—Mail Lines ...	12,447	3,370	2,128
Other Lines	4,659	8,548	9,489
Total	17,107	11,918	11,618
Total—Mail Lines ...	13,618	3,798	2,204
Other Lines	5,525	9,977	10,540
Total	19,143	13,775	12,744
	lb.	lb.	lb.
Load Transported—			
Mail	459,458	299,666	328,618
Freight and Goods ...	764,449	1,870,136	2,522,233
Total	1,223,908	2,169,202	2,850,851
	lb. miles.	lb. miles.	lb. miles.
Pound-Miles—			
Mail	83,373,154	61,140,151	64,227,154
Freight and Goods ...	90,522,553	220,401,058	280,477,396
Total	173,895,707	281,541,209	344,704,550
Passengers Carried (Revenue only)—			
Mail Lines	2,371	807	837
Other Lines	5,676	8,156	16,105
Total	8,047	8,963	16,942
	Pass. miles.	Pass. miles.	Pass. miles.
Passenger-Miles—			
Mail Lines	496,245	98,622	66,053
Other Lines	615,383	899,997	1,028,548
Total	1,111,628	998,619	1,094,600
	Miles.	Miles.	Miles.
Mail Line Efficiency—			
Scheduled distance ...	1,336,249	382,860	207,075
Productive distance flown	1,224,440	329,694	203,533
Lost distance	111,809	53,167	3,542
Percentage of Schedule Efficiency	91.63%	86.1%	98.3%

The Bulletin, Canadian Airways, Ltd., 15/2/34.

India

	Length of air routes in operation.	Weekly scheduled mileage.
1930	700	1,400
1931	700	1,400
1932	2,020	4,040
1933	3,970	11,140

These figures exclude the mileage operated by the two foreign companies, the K.L.M. and Air France, whose services cross India over a route, for all practical purposes, common to all three trans-India services.

In 1929, Imperial Airways opened the first service to India, for mails and passengers, subsidised by the British Government. At the same time, the service was extended to Delhi via Jodhpur as a State-managed Air Service—the aircraft (De Havilland Hercules type) being chartered from Imperial Airways.

In 1930, both the Dutch and French companies began operating experimental services, which eventually developed into the regular weekly services from Amsterdam to Batavia and Paris to Saigon, which are now an important feature on the trans-India route.

During 1931 steps were taken to organise an Indian State Air Service between Karachi and Calcutta, which was intended to replace the Karachi-Delhi Service. Machines were built, but the retrenchment which was forced on Government necessitated the abandonment of the scheme. Since the Karachi-Delhi Service terminated at the end of 1931, a temporary arrangement was made with the Delhi Flying Club to carry on the service, for the carriage of mails only, with a light aeroplane; and this service was operated until July, 1933.

In October, 1932, Tata Sons, Limited, opened the Karachi-Bombay-Madras Air Mail Service, a route of 1,320 miles in length, under a ten-year contract with Government. It is worth recording that Tatas had endeavoured since 1928 to establish this service, and that it has operated with 100 per cent. efficiency since its inception. The service is not subsidised, and the only support which the operators receive is in the form of payment for carriage of mails at contract rates.

In July, 1933, the first section (Karachi-Calcutta) of the trans-India Service, operated by Imperial Airways and Indian Trans-Continental Airways, was opened; in October it was extended to Rangoon, and in December to Singapore.

On the 1st December, 1933, Indian National Airways opened their daily service between Calcutta and Dacca, and a weekly service between Calcutta and Rangoon, duplicating a section of the main trans-India service. These services have been established without subsidy and on the basis of a short term agreement for the carriage of air mails.

It will be seen that the main structure of the organisation in India consists of an Indian company, Indian Trans-Continental Airways, Limited, formed for the purpose of operating, with Imperial Airways, Limited, the Karachi-Singapore section of the service from England to Australia; Tata Son, Limited (Aviation Department), who so far have the field in South India practically to themselves; and Indian National Airways, who have a secured position in North India.

The jointly operated trans-India service is subsidised by the British Government, with assistance in the matter of remission of customs duty and landing fees by the Government of India. By granting the remission of duty and fees, very substantial reciprocal benefits were secured by the Government of India, in the settlement of accounts for the carriage of mails in sterling instead of in gold. Alternate services are operated by Imperial Airways and Indian Trans-Continental Airways, the capital of which is held jointly by the Government of India, Imperial Airways and Indian National Airways. The latter company, as part of the arrangement whereby they invested capital in Indian Trans-Continental Airways, hold a concession from Government that they will be given the first option on any offer of an air mail contract or subsidy for air services in a zone within India,

to the north of the main route. This concession lasts till the termination of the main trans-India agreement, namely, March, 1939.

It may probably be asked why the main services across India should need a subsidy while the internal services receive none. The answer, in the first place, is that the Government of India have not been in a position for some years to offer a subsidy for the development of air transport. The development in internal services which took place therefore had perforce to be along lines which reduced operating costs and showed a fair prospect of early filling of load carrying capacity. On routes which did not show such a prospect, services could not be operated. As against this, the main Empire service has to be operated as a combined passenger and mail service, with a high standard of comfort and technical organisation and a large margin of load carrying capacity from the start, so to provide for the very much greater development which must ultimately be required on this route. For this reason the British Government have subsidised the Empire Air Services.

Statistics.	Weight of air mails to and from India. Tons.	Number of passengers to and from India.	Value of goods including bullion imported and exported by air. Rs.
1929	18.8	No record.	No record.
1930	32.8	148	No record.
1931	39.1	204	17,16,478
1932	41.4	407	33,41,105
1933	52.4	738	53,84,552

Of these, the most significant figures are those relating to mails, practically all of which in the outward direction and the majority of which in the inward direction, are carried by Imperial Airways from and to Karachi. Of the value of imports and exports a considerable proportion of the imports consists of precious stones, while in 1932, a quantity of gold was exported by air.

The most striking example of the growth of air mails is provided by the Tata Air Service, which in 18 months has more than trebled its traffic.

Quarter ending	Weight of mails. lb.
31st December, 1932	2,975
31st March, 1933	3,918
30th June, 1933	4,360
30th September, 1933	6,302
31st December, 1933	8,905

A considerable impetus to the air mail traffic was provided by the Indian Posts and Telegraphs Department in 1933, by the simultaneous reduction of oversea air mail surcharges and abolition of the special surcharge for carriage to Karachi. This had the effect of diverting the whole of the foreign air mail from the areas served by the internal services on to those services. We are now watching the effect of the reduction of the internal air surcharge from 2 annas to one anna per $\frac{1}{2}$ tola letter, which took effect simultaneously with the reduction of the inland postage on 1st April, 1934. The Calcutta-Dacca daily service should prove a useful testing ground.

The connection of North-West India with the main European air service is an obvious necessity. It is the only remaining region in India to be connected, and, though its traffic will not equal the South India traffic, the potential traffic is sufficient to establish the service on a solid foundation. No large scale development of long distance internal air services can take place without the development of night lighting organisation, and this involves large scale expenditure of funds.—*Indian National Airways Gazette*, May, 1934.

New Guinea

Airways in New Guinea

For the year ended 31st December, 1933, it is reported that 4,300 tons (4,369,000 kg.) of cargo were transported inland, also 3,600 white passengers and 4,000 natives were carried by Guinea Airways in that part of New Guinea which is Australian mandated territory.

The gold fields of New Guinea are, in many respects, unique in the progress of aviation. This country is one of the least known parts of the world, and the gold fields are situated in an almost inaccessible and impenetrable jungle, behind mountains running up to 6,000 ft. (1,829 m.) and surrounded by head-hunting cannibals. The air route from the coast is only some 60 to 70 miles (96 km. to 112 km.), half-an-hour's flying, but before aeroplanes were used everything had to be carried up by porters, the journey taking about ten days. After the discovery of gold it was estimated that it would take more than two years to construct a road from the port to the fields; owing to the very heavy rainfall (200 to 300 inches—5,080 to 7,620 mm.—annually) the upkeep would have been almost prohibitive and the cost of construction enormous. After much consideration it was decided to use aeroplanes to transport all the machinery necessary for the mining operations; at first small machines were used, but later it was found more economical to employ large aeroplanes with a carrying capacity of $3\frac{1}{2}$ tons (3,556 kg.). Difficulty was found in loading cumbersome boilers and turbines, and special bodies had to be constructed into which they could be loaded by crane. The fleet consists of three three-engined and three single-engined Junkers, two Fox Moths and two Moths.

Six trips, with a total load of 16 tons (16,257 kg.) is the daily routine for the large machines, and one of the smaller type has made as many as 11 trips a day with a total load of $9\frac{1}{2}$ tons (9,652 kg.).

The Australian Government has decided to call for tenders for the establishment of a fast seaplane service to link up all coastal and island ports in New Guinea.—*Journal of the Aero Club of India and Burma, Ltd.*, May, 1934.

Belgium

S.A.B.E.N.A.—1933 Results

The following information has been received from the Administration de l'Aeronautique, Brussels:—

	Europe (12 months).	Africa (10 months).
Flying time	... 7,190 hrs. 40 mins.	840 hrs. 5 mins.
Distance flown	... 1,098,238 km. (682,412 miles)	129,835 km. (80,676 miles).
Number of passengers	11,212	1,048.
Passengers ...	... 348,954·5 tonnes/km. (213,428 ton/miles)	68,383 tonnes/km. (41,824 ton/miles).
Merchandise	... 317,343 kg. (312.32 tons)	8,770 kg. (8.63 tons).
Merchandise	... 100,094.94 tonnes/km. (6,122 ton/miles)	7,343 tonnes/km. (4,491 ton/miles).
Mail and parcel post	31,920.80 kg. (31.42 tons)	24,989 kg. (24.59 tons).
Mail and parcel post	12,317·75 tonnes/km. (7,534 ton/miles)	18,700 tonnes/km. (11,437 ton/miles).

S.A.B.E.N.A.—Subsidies

Ministerial order dated 18th October, 1933, establishing the subsidies allocated by the State to the Sabena for the operation of the Belgium-Congo air service during 1932.

In pursuance of the law of 18th June, 1932, setting forth the budget of the Ministry of Transport for the 1932 financial year;

After consideration of the Ministerial order of 3rd October, 1933, establishing the total subsidy allocated to the Sabena for the operation of the Belgium-Congo air service during 1932;

Taking the view that the charges in connection with the endowment of the fund for renewal of the flying material destined for the Belgium-Congo air service should not be taken into consideration and that provision should only be made for the charges in connection with the service of the portion of the debenture loan utilised for the acquisition of certain elements of the said material;

Hereby decrees:—

Sole Article.—The subsidy allocated to the Sabena for the Belgium-Congo air service for the 1932 financial year is reduced from 715,215.15 francs (£4,087) to 93,294.80 francs (£533). The said sum representing the charges in connection with the service of the portion of the debenture loan utilised for the acquisition of certain elements of material for the Belgium-Congo air service.—*Moniteur Belge*, 12/4/1934.

Ministerial order dated 27th December, 1933, establishing the subsidies allocated by the State to the Sabena for the company's operations in Europe during 1933.

Hereby decrees:—

Sole Article.—The total subsidy allocated to the Sabena for 1933 is fixed at 16,611,904 francs (£94,925).—*Moniteur Belge*, 18/4/1934.

Ministerial order dated 15th March, 1934, establishing the subsidies allocated by the State to the Sabena for the operation of the Belgium-Congo air service during 1933.

Hereby decrees:—

Sole Article.—The total subsidy allocated to the Sabena for the Belgium-Congo air service for the financial year 1933 is fixed at 260,588.45 francs (£1,489).—*Moniteur Belge*, 18/4/1934.

Danish

Danish Air Traffic Company (Det Danske Luftfartselskab A/S.)—Returns for 1932 and 1933

Distance Flown—

		1932. Miles.	1933. Miles.
On routes according to time-table.	Day-time...	129,511	113,624
,, ,, ,,	Night-time	22,384	16,681
,, additional ,,	... ...	4,679	5,247
On trip flying		3,772	2,948
Total commercial flying		160,346	138,500

Passenger Traffic—

	1932. Persons.	1932. Pass./Miles.	1933. Persons.	1933. Pass./Miles.
Passengers carried on route by time-table	3,443	421,864	4,457	584,207
Passengers carried extra to time-table	159	13,080	495	29,998
Passengers carried on trip flying ...	1,383	27,499	1,052	20,917
Total	4,985	462,443	6,004	635,122

Commercial Traffic—		Tons.	Ton/Miles.	Tons.	Ton/Miles.
Carried on routes.	Passengers ...	254.64	31,420	350.93	45,974
,, ,,	Freight* ...	21.88	4,067	20.00	4,273
,, ,,	Luggage ...	28.89	5,253	34.36	7,349
,, ,,	Mails* ...	23.72	5,462	22.82	5,874
Aggregate freights carried on routes		329.13	46,202	428.11	63,470
* Includes cargo on night post routes.					
Carried on night post routes (included in * above)—Mails ...		13.58	3,677	12.88	3,690
Freight ...		1.81	490	2.37	679
Aggregate weight carried on night post routes		15.39	4,167	15.25	4,369
Carried on extra flights—					
Passengers		12.52	1,030	38.97	24,284
Luggage, freight and mails ...		1.37	190	0.48	83
Aggregate weight carried on extra flights		13.89	1,220	39.45	24,367
Regularity of traffic		98.04%		97.23%	

In route traffic the increase amounts to:—

Number of passengers	29.45%
Passenger/kms. (or passengers/miles)	38.48%
Post, freight and luggage. Weight	3.61%
,, ,, ,, Ton/miles	18.37%
Total aggregate weight	30.07%
,, ,, Ton/miles	37.38%

Finland

Traffic Results of Aero O/Y for the year 1933

Route.	Distance flown.	Number of passengers carried.*	Weight of mail carried.*	Luggage and goods carried.*
Helsingfors-Abo-Stockholm	48,554	1,642	9.57	30.14
Helsingfors-Tallinn	30,590	2,558	2.25	26.10
Stockholm-Malmo (Night Mail Service)	59,912	—	12.74	3.15
Special flights	3,952	187	—	—
Total	143,008	4,387	24.56	59.39

* Figures are "actual."

During the year 1933 Aero O/Y has received in State subsidies Fmks. 2,078,900 (£82,431), and in municipal supports from the City of Abo Fmks. 40,000 (£1,580).

The income, not counting subsidies, was Fmks. 3,464,675:15 (£137,379), thereof Fmks. 1,457,709:10 (£57,799) for transport of mail. Though the number of kilometres flown in 1933 was only 230,149 (143,008 miles) or 16 per cent. less than in 1932, the income from passenger traffic rose by 11 per cent. and from mail by 8 per cent.

At the end of 1933 the company's aeroplanes had reached the following datum of performance:—

OH-ALK	" Sampo "	849.2 hours	96,313 miles
OH-ALC	" Suomi "	2,960.07 ,,	277,132 ,,
OH-ALF	... ...	2,154.55 ,,	201,324 ,,
OH-ALI	... ...	2,309.41 ,,	213,130 ,,

Dept. of Overseas Trade, February, 1934.

France

French Air Traffic

Statistics show that on the whole French air traffic reached its peak in 1931, fell in 1932 and recovered slightly in 1933.

The system operated in 1933 covered 35,000 kilometres (21,748 miles) as compared with 40,100 (24,916 miles) and 12,100 (7,518 miles) respectively in 1932 and 1926. The total distance covered last year was 9.7 million kilometres (6 million miles) as against 10.5 million (6.5 million miles) in 1931 and 5.2 million (3.2 million miles) in 1926.

In 1933 the number of passengers reached the record total of 50,400 as compared with 13,650 in 1926. Freight amounted to 1,513 tonnes (1,489 tons) as against 1,162 tonnes (1,143 tons) in 1932, 2,500 tonnes (2,460 tons) in 1931 and 760 tonnes (748 tons) in 1926. The figures for mail were 211 tonnes (207 tons) as compared with 173 (170), 256 (252) and 154 tonnes (151 tons) respectively.

There has been a considerable increase during the last ten years in yield in terms of average distance per pilot and per machine, no doubt on account of higher speed. The average distance per pilot was 40,550 kilometres (25,197 miles) in 1924, 96,450 (59,932 miles) in 1931, 70,000 (43,496 miles) in 1932 and 88,100 (54,742 miles) in 1933, while the distance covered per machine has risen from 14,000 (8,700 miles) in 1924 to the record figure of 39,000 (24,233 miles) in 1933.—*Les Echos*, 31/1/34.

Italy

Civil Aviation Statistics, 1933

The following details have been obtained from the Italian Air Ministry:—

(*a*) Miles or kilometres flown ... ... 5,660,302 km. (3,517,149 miles)
(*b*) Number of passengers carried ... 42,645
(*c*) Weights of goods and newspapers carried—
  (i) Newspapers carried ... 238,255 kg. (234.49 tons)
  (ii) Goods carried ... ... 187,596 kg. (184.63 tons)
(*d*) Weight of mail carried ... ... 62,656 kg. (61.66 tons)

(The above figures are " actual.")

491 *Civil Aircraft Entered in the Italian Register*

In the last twelve months also the I.N.A.R. has issued 140 Certificates of Airworthiness and as many Classification Certificates for powered aircraft, and 101 for gliders—all after regular supervision and acceptance tests.

On 15th April, 1934, the aircraft entered in the Register were 63 for civil air lines, 304 school and private machines, 124 gliders; total 491.

The technical operations carried out by the officials of the I.N.A.R. for the technical control of all these aircraft consisted of 1,480 special inspections, 4,370 factory inspections of machines, and 3,720 of engines; 1,550 test flights, the latter with a total duration of about 1,300 hours. Although this is an imposing array of operations, it only constitutes part of the work carried out by the Section, which includes various work of verification, assistance, technical consultation, and research—all in the interests of civil aviation.

Certain regulations issued during this period deserve special mention. In April, 1933, the Air Ministry fixed the limits of employment of aircraft and engines used on air lines, on the basis of statistics supplied by the I.N.A.R.; as a consequence of these limits, three Wal, three S.55 and one F.13, and a fair number of engines, were deleted from the register during the year, which helped to keep the air fleet up to date.

In order to estimate the actual condition of a machine which had reached the age limit, a test to destruction was carried out on one of the S.55 deleted from the register; this showed that it had lost less than 10 per cent. of its original strength, which demonstrates that the safety was not appreciably reduced.

Another rule of a general nature was that machines operating air lines should not in normal flight use more than 7/10 of the acceptance test power of the engines, in order to ensure their better preservation and regularity of operation; the I.N.A.R. arranged, by suitable calculations and tests, to establish for each type the number of r.p.m. corresponding to the said 7/10, which was not to be exceeded in normal flight.

Finally, a recent Royal Decree (No. 2348, dated 18th December, 1933), on the basis of technical data supplied by the I.N.A.R., regularised the question of engineless aircraft, for which the name of gliding machines (aliante) was accepted, and which were subdivided into sail-planes and gliders; for purposes of simplification, the I.N.A.R. will only issue its acceptance certificate for the latter, instead of the Certificate of Airworthiness.

Drafting of Technical Regulations

Simultaneously with the daily work of surveillance, the Aeronautical Section has continued the drafting of technical regulations and various publications, making use of the remarkable collection of experience and accurate data at its disposal through the service of the officials. The principal ones may be cited:—

1933 Register of civil aircraft, published in April, 1933, followed by regular quarterly supplements.

Regulations governing the static tests of aircraft, published in May, 1933, after due approval by the Air Ministry, and now regularly applied by all constructors.

Regulations governing the acceptance flight tests of aircraft, approved by the Ministry on 15th February, 1934, and entered into force at once.

Manual of the Aeronautical Inspector, with full instructions for technical inspections, published 1st July, 1933.

Technical monographs on the aircraft for air lines; one on the Fokker F.VII machines was published in 1933, and one on the Junkers machines in 1934.

The Italian translation of the " Regulations governing the minimum requirements for the issue of the Certificate of Airworthiness " of the I.C.A.N., which has force of law in Italy, was also published in 1933.

The new regulations governing the testing and acceptance of engines for civil use are being drawn up, and will soon be applied.

With these various publications, the Register not only maintains the necessary contacts with the requirements of technical control, laying down rules and elements of comparison, but also frequently takes the initiative—as in the case of the regulations for qualification for various categories of flight—the better to direct the evolution of civil flying material, to which it is giving increasingly assiduous care.—*Le Vie dell 'Aria*, 29/4/34.

Netherlands and Netherlands East Indies

Schiphol Aerodrome Statistics for 1933

The number of passengers increased from 18,420 in 1932 to 30,640 in 1933, *i.e.*, by about 66 per cent., the 1933 total including 8,743 passengers in transit, against 5,525 in 1932.

Goods traffic increased by nearly 33 per cent., namely, from 1,007,000 kg. (991 tons) in 1932, to 1,337,000 kg. (1,316 tons) in 1933.

Mail transport increases steadily, and amounted to 130,400 kg. (128 tons) in 1933 as against 128,600 kg. (127 tons) in 1932. About a quarter of the 1933 total was carried on the Dutch East Indies air line.

345 sports and touring aeroplanes touched at Schiphol during 1933, as against 295 in 1932.—*De Telegraaf*, 11/1/1934.

K.L.M. Provisional Report 1933

A provisional report has been published by the K.L.M. (Royal Dutch Air Service) for the year 1933.

Holland—N.E. Indies Route

The average duration of the journey Amsterdam-Batavia has been reduced to 9.9 days outward and 9.2 days inward. For 1932 these figures were 10.6 and 9.63.

It is proposed to bring an improved type of aeroplane into service, which besides providing more comfort for passengers will have a greater cruising speed of 30 km. (18 miles). Moreover, it is intended to introduce night flying on the Indian route. Reduction of the fare appears to be contemplated.

Postal traffic has increased and in 1933 amounted to 44,523 kg. (95,156 lbs.), or 9,227 kg. (20,342 lbs.) or 26 per cent. more than in 1932.

The number of passenger/km. flown was 3,624,161 (2,251,953 pass./miles), which shows an increase of 1,899,317 pass./km. (1,180,183 pass./miles) or 10 per cent.

The quantity of goods carried rose from 4,971 kg. (10,959 lbs.) to 9,193 kg. (20,267 lbs.) or 85 per cent. more.

New Aircraft

Two new types of aeroplanes are in the course of construction—F.36 (16 passengers) and F.22 (10 passengers).

The F.36 will have geared motors and flexible propellers.

European Lines

The K.L.M. carried 40,082 passengers, as against 20,877 in 1932; an increase of 92 per cent.

Goods traffic: 865,048 kg. (851 tons), as against 1,196,257 kg. (1,177 tons) in 1933. Increase, 38 per cent.

Postal traffic: Increased from 134,525 kg. (132 tons) to 147,261 kg. (145 tons), or 9 per cent.

In 1933 the K.L.M. improved the London-Amsterdam-Berlin service which proved to be a success.

Inland Traffic.

Conveyance of passengers: 10,800, as against 2,500 in 1932. Joy flights were taken by 13,706 passengers.—*Dept. of Overseas Trade*, January, 1934.

Dutch National Flying School: Extracts from 1933 Annual Report

The results in 1933 exceeded all expectations.

	1932	1933
Number of flights	4,486	5,793
Number of flying hours	1,854	2,501
New pupils	59	80
"A" Certificates issued	21	28
Number of aeroplanes on 1st January ...	7	10
Number of privately owned aeroplanes ...	17	24

The number of instructors was increased to six; two instructors are shortly to be trained at Soesterberg, if authorisation can be obtained from the competent authorities. The N.L.S. received permission from the Minister of Defence to borrow two military aeroplanes in case of emergency.

The N.L.S. was granted a State subsidy in 1933, and is to receive the same amount in 1934.—*Dutch Press.*

Increase of Traffic on Dutch East Indies Route

A comparison of the traffic figures for the K.L.M. route to the Dutch East Indies shows that during the first quarter of 1933 the number of passengers/km. was 676,733 (420,502 pass./miles) and in 1934 930,124 (577,953 pass./miles), representing an increase of 37 per cent. The number of tonnes/km. of mails increased from 111,695 (68,315 ton/miles) to 123,119 (75,302 ton/miles) in 1934, *i.e.*, by 10 per cent. Goods traffic also increased from 11,784 tonnes/km. (7,207 ton/miles) to 16,597 tons/km. (10,151 ton/miles) in 1934, *i.e.*, by nearly 41 per cent.—*De Telegraaf*, 7/5/34.

K.N.I.L.M. 1933 Report

If the present economic conditions are taken into account, the results obtained during 1933 on the regular air routes may, generally speaking, be regarded as satisfactory. The number of passengers was approximately the same as in 1932, the average bookings were 2 per cent. higher, freight transport increased 5 per cent., and mail transport 25 per cent. The detailed traffic figures are as follows:—

Air Line.	Passengers.	Goods.		Mail and Parcel Post.	
		kg.	lb.	kg.	lb.
Batavia-Bandoeng (twice daily) ...	2,836	29,613	64,075	883	1,947
Bandoeng-Batavia ,, ,, ...	3,086	12,749	26,638	836	1,843
Batavia-Samarang-Soerabaya (daily)	1,408	5,071	11,180	5,771	12,723
Soerabaya-Samarang-Batavia ...	1,547	7,782	17,156	5,319	11,726
Batavia - Palembang - Singapore (weekly)	280	5,309	11,704	506	1,116
Singapore - Palembang - Batavia (weekly)	276	1,375	3,031	669	1,475
Batavia - Palembang - Pakanbaroe - Medan (weekly)	289	5,591	12,326	5,182	11,424
Medan - Pakanbaroe - Palembang - Batavia (weekly)	211	1,341	2,956	1,830	4,034
Meden-Alorstar (weekly as from 4/5/33)	39	74	163	1,278	2,817
Alorstar-Meden (weekly as from 4/5/33)	43	45	99	1,278	2,817
Special flights	568	118	260	733	1,616
Circular flights	2,554	—	—	—	—
Total	13,137	69,068	152,269	24,279	53,526

Regularity of the Services

The regularity was 100 per cent. on all lines except the Bandoeng and Medan lines; on the Bandoeng line the regularity was 99.76 per cent. On two occasions very bad weather prevented flight through the mountains, and on one occasion the return flight from Bandoeng to Batavia had to be cancelled. Owing to the aerodrome being waterlogged, the undercarriage of a machine was damaged in landing at Pakanbaroe, with the result that one flight between Batavia and Medan

could not be completed on the day of departure. Hence the regularity on the Medan line was 99.04 per cent.

During 1933, 2,294 flights in 5,339 flying hours were carried out, the distance covered being 863,698 km. (536,678 miles). The total distance flown by K.N.I.L.M. machines up to 31st December, 1933, was 3,992,780 km. (2,481,001 miles), *i.e.*, 100 times round the world. 938,000 tons/km. (573,089 ton/miles) were carried in 1933.

Passenger Traffic

During 1933, traffic on the Bandoeng line decreased. This was, however, not unexpected, as this service is mainly patronised by holiday-makers. The number of passengers on the Medan line decreased slightly, but on the other hand there was a considerable increase on the Soerabaya and Singapore lines. Approximately half the passengers took return tickets.

During 1933 the company again had the honour of conveying the Governor-General on several occasions. Other notable passengers included the Governor of the Straits Settlements, the ex-Governor of the Philippines, Prince Palibatra of Siam, etc.

Rates

The passenger fare between Batavia and Bandoeng was, as from 15th December, reduced from 17.50 Fl. (£1 9s. 0d.) to 12.50 Fl. (£1 0s. 8d.), single, and from 30 Fl. (£2 9s. 0d.) to 21.25 Fl. (£1 15s. 0d.) return; the rate for freight was reduced to 0.15 Fl./kg., minimum 1.25 Fl. (3d. per 2.2lb., minimum 2s. 0d.). Since 20th June, 1933, freight has been rounded up to ½ kg. (1 lb.) instead of to a full kg. (2.2 lb.) in calculating the amount.

In December a system of discount for passengers was introduced, in accordance with which discount is allowed to regular patrons at the end of each year, the said discount being calculated on a progressive scale, according to the amount paid for air fares.

The K.N.I.L.M. maintained the reduction of the fare for passengers travelling between Batavia and Medan to catch the mail steamers, even after the reduction of the rates by the shipping companies. Thanks to this, the difference in cost of the voyage from Batavia to Europe by steamer, and that of the same journey—making the stage Batavia to Medan by air—thus saving three days, is only 80 Fl. (£6 12s. 0d.).

Freight

Transport of flowers from Bandoeng to Batavia, Palembang and Singapore decreased. On the other hand, carriage of newspapers increased between Batavia-Bandoeng and Palembang, and a larger number of films were carried on all lines. The final figures were higher than in 1932.

Mails

Except on the Medan line, carriage of mails increased on all lines. The decrease on the Medan line was due to the change in the day of departure of the K.L.M. aeroplane from Batavia for Holland, which, since May, has been altered to Wednesday, which is the day on which the mail boats leave. This did away with the advantage of sending air mails on Saturdays by K.N.I.L.M. aeroplane to Medan to catch the mail boat. In contrast to the decrease on the Medan line, there was a great increase in air mails on the Soerabaya line to connect with the K.L.M. aeroplane.

K.L.M. Netherlands-Dutch East Indies Line

The flights on this line were operated with 100 per cent. regularity. As from the beginning of May, the service was operated via Singapore, instead of Medan, and the aeroplanes left Batavia on Wednesdays. In addition, the duration of the journey westwards was reduced to eight days during the summer season, and a connection to London arranged on the day of arrival at Amsterdam.

The service was operated with five F.XVIII and two F.XII aeroplanes.

As from 1st November, the freight rates were considerably reduced, *i.e.*, to 8.30 Fl. per kg. (13.9d. per 2.2 lbs.).

The number of passengers doubled, compared with 1932, and amounted to 772 passengers on the various stages. Of the three million seats/km. (approx.) (1,864,000 seats/miles) on the westward journey, nearly two million (1,242,700 seats/miles) were booked. This represents an average booking of 67 per cent. During certain months these bookings amounted to over 90 per cent. In the case of several machines, would-be passengers had to be refused as all seats were booked. The average amount of air mails despatched weekly from the Dutch East Indies increased from 225 kg. to 262 kg. (496 to 577 lbs.) per week; that from the Straits Settlements and Federated Malay States, from 38 to 76 kg. (84 to 168 lbs.).

The " Pelikaan," in place of the much smaller " Zilvermeeuw," made the outward flight in 100 hours 40 minutes, and the homeward flight in 100 hours 34 minutes, thus breaking all previous records between Batavia and Amsterdam. Over half a tonne (half a ton) of air mails was despatched from the Dutch East Indies to the Netherlands by the " Pelikaan."

Norway

Norwegian Ministry of Defence Estimates

The Government have allocated 38,000 kroner (£2,094) to civil aviation, 17,600 (£970) less than for the present financial year, as nothing has been decided about the Gressholmen air port and Kjeller aerodrome. In view of the economic crisis, the Government have decided not to grant the mail and State subsidy of 500,000 kroner (£27,548) a year for ten years, applied for by the Fred. Olsen Norwegian Air Transport Co. The Naval Air Service grants include 25,000 kroner (£1,377) for the construction of new seaplanes.—*Tidens Tegn*, 19/1/34.

Spain

Summary of Traffic on the " L.A.P.E." Air Routes, 1932 and 1933

	Length of route.	Hours of flight.	No. of journeys carried out.	Distance flown.	Passengers.	Mails.	Magazines, etc.	LUGGAGE. Passengers. Free Allowance.		Paid Excess.		Crew.		Total.		Goods.	
	Miles.			Miles.		Tons.	Tons.	Kg.	Tons.	Kg.	Tons.	Kg.	Tons.	Kg.	Tons.	Kg.	Tons.
1932	1,143	4,059	1,322	378,912	6,374	86.94	12.51	40,652	40.01	4,745	4.67	11,819	10.91	57,216	56.31	23,963	23.58
1933	1,143	3,458	1,139	325,120	4,496	70.01	1.81	33,147	32.62	5,704	5.61	—	—	38,851	38.24	22,951	22.59
% Inc. or dec.	—	−15%	−14%	−14%	−29%	−19%	−86%							−32%		−4%	

Spanish Air Traffic during 1933

Spanish air traffic during 1933 was in the hands of the " Lineas Aereas Postales Espanoles," a commercial company whose capital is all held by the

State, but which is governed by the regulation of the Commercial Code and operates as a private company, controlled by a State Delegation, and subject to the general rules which the Directorate of Aviation, the State organisation responsible for air traffic, establishes for all operating companies.

From the beginning of the year the Madrid-Seville and Madrid-Barcelona lines were operated daily, Sundays excepted, the object being to employ the kilometric subsidy thus saved, towards the establishment of the Seville-Canary Isles line during 1933, since no increase was made in the 1933 budget over that of previous years, for the operation of air lines. By this means a subsidy was available which would have enabled the inauguration of the service in September, 1933, but owing to delay on the part of the contractors in the provision of material the line was not operated until December. The machines for use on this line are three Fokker three-engined aeroplanes fitted with Serval 360 h.p. engines, and equipped with D/F., long and short wave W/T. apparatus, instruments for blind flying, and petrol tanks with a total capacity of 1,500 litres (330 gals.). In flying order (weight 5,500 kg.) (5.41 tons) these machines can take off on two engines, and they have a practical ceiling of 3,000 metres (9,843ft.) with the same power.

The fleet operating the lines within the Peninsular consists of five three-engined Fokker and Ford machines (Spanish Wright engines), with a pay load capacity of 1,050 kg. (1.03 tons). Their endurance is five hours.

The number of km. flown was 536,590 (333,421 miles), of which 10,600 (6,587 miles) were on the Seville-Canary Isles line and the remainder on the Peninsular lines. The total number of hours of flight was 3,576, representing 10,728 hours' running of the engines, during which there were only two cases of engine trouble, neither of which entailed landing.

The number of flights completed was 1,150, with an additional 13 which were interrupted, *i.e.*, during which intermediary landings at emergency landing grounds were necessary on account of weather conditions. There was also one forced landing in open country due to trouble in the petrol system. There were no accidents to personnel or material, hence Spanish air lines maintained their splendid tradition of absolute safety, there having been no loss of life on the services up to the present.

The excellency of the pilots was again shown by the fact that there were only two faulty landings during the year, causing damage to the extent of only 4 and 2 per cent. of the value of the machine.

The number of passengers carried was 4,451, the amount of mails 70 tons and of goods 60 tons, representing utilisation of 48 per cent. of the available load. The regularity of flights, *i.e.*, the proportion of flights carried out in relation to the number authorised by the Government was 98 per cent.

The operational expenditure was surprisingly low, the cost per tonne/km. being 5.80 pesetas or 2.10 pesetas gold (2/8.7d. per ton/mile), a much lower figure than that of other companies. The commercial receipts covered 38 per cent. of the total expenses which, when compared with the 48 per cent. utilisation of the available load, shows that the company is on its way towards becoming self-supporting. This would, in fact, be possible in Spain if, as in other countries, the company received the air mail fees. The number of letters carried was over 4 million, for which the fee without the surcharge is 1,200,000 pesetas (£47,581), whilst the subsidy granted to the L.A.P.E. was 2,100,000 pesetas (£83,267). Undoubtedly, if the company had been allowed to establish the lines which it wished to operate, as for instance one from Madrid to Valencia and one from Madrid to the North of Spain in the summer, which would have been more lucrative, and if it were to receive the air mail fees, the air lines would not require subsidisation.

The following is a summary of statistics as from May, 1929, when operation of the air lines commenced, up to the end of 1933:—

Kilometres flown	2,686,000 (1,669,008 miles)
Passengers carried	27,003
Freight, mails and baggage (tonnes) ...	487 (479 tons)
Number of flights operated	5,723
Number of flights with intermediary landings	118
Landings in open country	7
Faulty landings involving damage to aircraft	2.1
Number of hours' running of engines	44,200
Accidents	Nil.

Revista de Aeronautica, February, 1934.

Sweden

A.-B. Aerotransport—Annual Report for the year 1933

The following has been extracted from the 1933 Annual Report of A.-B. Aerotransport:—

During the year the company has conducted regular air services on the following routes:—

Malmo-Amsterdam	From 1st January to 31st December.
Stockholm-Helsingfors	,, 15th April to 12th December.
Stockholm-Visby	,, 1st July to 1st September.
Stockholm-Malmo (night mail service) ...	,, 1st May to 31st May.
Goteborg (Gothenburg)-Malmo (night mail service)	,, 1st June to 28th July.
Copenhagen-Malmo-Hannover (night mail service)	,, 1st May to 30th September.

In addition, short passenger trips and special chartered flights have been undertaken. This year, as last, a number of ambulance flights have been carried out from the Stockholm Air Port.

On the Amsterdam route aeroplanes of the Fokker F.XII and Junkers Ju. 52 types have been employed, on the Helsingfors route Ju. 52, and for the night air mail service Junkers F.13 and W.34.

The number of passengers and the quantity of goods carried by the company's aeroplanes during the year, and also the distance flown, will be seen from the following table:—

	Passengers.			Mail.		Freight and baggage.		Distance flown.	
Year.	Regular route traffic.	Other air transport activities.	Total.	Kg.	Tons.	Kg.	Tons.	Km.	Miles.
1933	8,297	1,759	10,056	81,875	80.59	182,112	179.24	589,535	366,535

On the Amsterdam route were carried 7,738 passengers, of whom 3,676 were carried by the company's aircraft, on the Helsingfors route 4,563 passengers, of whom 2,907 were carried by the company's aircraft, and on the Visby route 1,744 passengers, all by the company's aircraft. During the year no accident has occurred involving injury to passengers.

The year's business has yielded a profit of Kr. 235,568:25 (£12,979), and after Kr. 152,026:01 (£8,376) have been written off there remains a net profit of Kr. 83,542:24 (£4,603). As this net profit, after 10 per cent. thereof has been placed to Reserve Fund, exceeds by Kr. 40,148:02 (£2,212) 6 per cent. of the share capital, then, in accordance with para. 5 of the contract between the State and the Company, one-half of the surplus amount, that is to say, Kr. 20,074:01 (£1,106), is placed to a special "Subsidy Fund." According to the said contract, the money thus set aside, provided it is not required for covering losses incurred during the period 1934-1936, is to be paid at the end of the latter year to the Treasury.

The number of passengers and quantity of goods carried and distance flown by the company's aeroplanes during the period of ten years are as follows:—

Year.	Distance flown. Miles.	Passengers carried.	Luggage. Tons.	Freight. Tons.	Mails. Tons.
1924	100,304	6,111	4.03	1.26	1.19
1925	216,353	9,687	26.82	11.45	4.90
1926	212,455	10,176	43.08	13.96	9.92
1927	203,990	14,807	39.56	44.33	6.89
1928	209,170	14,948	37.36	51.37	15.45
1929	208,421	5,914*	48.59	38.65	54.33
1930	258,398	17,326	40.42	32.90	45.28
1931	310,961	19,624	29.68	43.26	65.25
1932	291,412	6,440*	70.94	39.99	54.24
1933	366,535	10,056*	114.52	64.72	80.59
Total	2,377,782	115,089	455.01	342.89	339.04

* The low figures for the years 1929, 1932 and 1933 are due to no " All Round Sweden " journeys being made in these years.

The number of ton-miles offered and paid for on the proportion of the capacity utilised and the number of passenger-miles paid for on all day-route services, *i.e.*, the company's entire operations with the exception of night mail flights and short round trips and charters, will be seen from the following table:—

Year.	Capacity offered. Ton/miles.	Capacity (passenger and goods) paid for. Ton/Miles.	Proportion of capacity utilised.	Passenger capacity paid for. Pass./miles.
1924	25,892	16,141	62.34%	184,997
1925	120,548	73,243	60.76%	682,406
1926	143,101	81,633	57.05%	756,142
1927	139,431	80,647	57.84%	653,526
1928	136,270	78,358	57.50%	592,556
1929	143,522	87,309	60.83%	715,080
1930	135,983	185,885	63.16%	656,519
1931	136,840	73,544	53.74%	493,840
1932	245,967	146,776	59.64%	1,190,040
1933	327,716	220,681	67.34%	1,896,721
	1,555,387	944,218	—	7,821,827

Total Income and Expenditure for the Entire Business during the years 1924-1933

(In 1,000's kronor)

Year	Capacity offered.	Traffic receipts and income from interest.	Subsidy.	Total income.	Expenditure, excl. amounts written off and rent of 'planes.	Amounts written off and rent of 'planes.	Total expenditure.	Loss.	Profit.
1924 ...	30,661	122	—	122	128	—	128	6	—
1925 ...	162,570	421	306	727	654	112	766	30	—
1926 ...	162,862	423	471	894	960	291	1,251	357	—
1927 ...	157,247	587	559	1,146	965	241	1,206	60	—
1928 ...	165,979	745	487	1,232	952	288	1,240	8	—
1929 ...	169,187	644	512	1,156	997	538	1,535	379	—
1930 ...	184,733	769	537	1,306	1,055	363	1,418	112	—
1931 ...	199,783	979	542	1,521	1,168	320	1,488	—	33
1932 ...	293,224	1,069	637	1,706	1,142	529	1,671	—	35
1933 ...	381,740	1,461	647	2,108	1,401	623	2,024	—	84
1924-33	1,907,986	7,220	4,698	11,918	9,422	3,305	12,727	961	152

Note: 1,000 kronor = £55 (approx.).

Switzerland

"Alpar Bern" Air Transport Company, Fifth Annual Report, 1933

The following has been extracted from the 1933 Annual Report issued by "Alpar Bern" Air Transport Company:—

The year 1933 concludes the fifth period of operation. On looking back to the commencement of operation, in the summer of 1929, the Biel-Basel thrice-weekly air service was opened and the hangar at Belpmoos Aerodrome was still in course of erection. It is particularly satisfactory to note that the operational results on the air lines and other air traffic increased in comparison with 1932, in spite of the economic crisis. This is sufficient proof of the growing faith of the public in air transport. It is hoped that the support given to air transport by the federal, cantonal, and municipal authorities will bear further fruit, and that the present unfavourable economic conditions will not necessitate measures which would retard the development of air transport. Particular attention should be paid to the fact that, as in previous years, no accident occurred in 1933, a year marked by flying accidents.

Air Services

A new air service via Bern was operated from 1st May to 31st October as follows:—

Bern-Zurich-St. Gallen. Operated by the Alpar Bern Co. in pool with "Aero St. Gallen," which connects Eastern Switzerland with the air services to Western Switzerland and Spain, and provides an important afternoon mail service from Bern.

In addition, the following air services not touching Bern were operated by the Alpar Bern Co.:—

Basel-La Chaux de Fonds-Lausanne-Geneva, daily as air mail service.

Lausanne-Geneva, in pool with "Aerotraffic S.A.," Geneva, daily as feeder line from Lausanne for the Geneva-Paris service.

The statistics for the air services are as follows (the figures in brackets relate to 1932):—

The number of scheduled flights was 1,877 (1,806), representing an increase of 4 per cent. (46 per cent.). The increase is due to the extension of the period of operation of the Lausanne-Bern service from five to six months, whilst the cancellation of the Bern-Geneva service was balanced by the new Bern-Zurich-St. Gallen service.

The total number of departures and arrivals increased by 257 persons, or 16 per cent., compared with 1932. According to the statistics, passenger traffic decreased, as the Geneva-Bern section of the Berlin service was cancelled, and Bern again became the terminus for the Berlin line, which reduced the number of passengers in transit through Geneva to Zurich. In actual fact, passenger traffic increased considerably, owing to the fact that the number of passengers for destinations abroad has increased in comparison with those for Swiss destinations. For example, this proportion was 1:4.4 in 1931, but 1:1.5 in 1933, passengers for abroad representing 140 out of every 750. This is the best proof of the considerable importance of Bern in international air traffic.

The total weight of mails via Bern was 33,110 kg. (32.59 tons), (20,642 kg. (20.31 tons)), *i.e.*, increase 60 per cent., and of freight, 12,998 kg. (12.79 tons) (19, 985 kg. (19.66 tons)), *i.e.*, decrease 35 per cent.

The quota had a very detrimental effect on freight traffic. This applied particularly to consignments of flowers from Holland, which always formed a large proportion of the air freight.

Swiss pilots and aircraft operating scheduled air traffic covered a total of about 180,000 km. (112,000 miles) (166,000 (103,000 miles)) in 1,253 flying hours (1,188). From the opening of the company's services, therefore, over 500,000 km. (311,000 miles) have been covered in scheduled flight, without accident. The regularity of operation was 99 per cent.

General Air Transport

The heavy traffic on the Alpar-Bern air services limited the number of machines available for circular flights, and in particular for participation in foreign air meetings. The fact that results were financially better was partially due to increased photographic work, which was carried out exclusively with the "Stadt Biel." One of the commissions in question was a number of air photographs of the Bielersee district and a large photograph of Biel town, placed by the Cantonal authorities.

Like the circular flights, light aeroplane traffic was approximately equal to that of 1932. Gliding, which took place on Saturdays and Sundays, increased considerably, however, 1,400 take-offs being recorded.

920 flights were carried out in 310 hours, on circular, alpine, and special charter flights, representing an increase of 70 per cent. compared with 1932.

The total amount of traffic at Bern Aerodrome includes a total of 10,360 departures and arrivals, and a total of 6,730 passengers leaving and arriving.

The aircraft traffic increased by 8 per cent. in comparison with 1932, whilst the passenger traffic remained the same.

Operational Results

	1. Scheduled Air Traffic.		2. General Air Traffic.		
Year.	Flying hours.	Distance flown, miles.	Flights.	Flying hours.	Passengers.
1929	96½	8,388	695	187	611
1930	349	29,453	810	249	1,514
1931	1,008	85,625	1,159	410	2,595
1932	1,187½	103,147	498	183	1,383
1933	1,253	111,847	1,686	397	1,806
1929-33	3,894	338,460	4,848	1,426	7,909

Swiss International Air Traffic Statistics

1. Express services throughout the season on the Zurich-Munich-Vienna line only; average speed 260 km./hr. (161 m.p.h.); utilisation of available passenger accommodation – 68 per cent.; utilisation of available tonnage – 63.4 per cent.

2. Statistics for Bern-Zurich-Stuttgart-Halle/Leipzig-Bern, plus statistics for Geneva-Zurich section of the Geneva-Zurich-Munich-Vienna express line.

From 1st October the Geneva-Zurich service had no connection at Zurich with Berlin, but connections with Munich-Salzburg-Vienna.

3. Zurich-Basle only from 1st September to 7th October; from 1st May to 31st August connections at Basle with Zurich-Basle section of the Zurich-Basle-Amsterdam line.

4. All flights carried out to schedule, including supplementary flights.

5. Including paying passengers (allowing 80 kg. (176lbs.) per passenger, including free luggage).

Total Results—Summer 1933

Lines.	Stages.	Distance flown. Miles.	Passengers.	Mail. Tons.	Freight. Tons.	Excess Baggage Tons.	Ton/Miles.
International Services Operated in Pool with Swiss Company	5,063	631,344	19,940	90.97	274.53	43.42	244,575
International Services in which Swiss Companies have no Share	1,802	280,819	8,285	29.26	72.48	24.70	132,374
International Experimental Services	388	60,719	671	17.72	2.40	1.07	11,630
International Services, Mail, but no Regular Passenger Transport	93	33,718	17	22.79	0.22	0.11	8,962
Internal Services	3,483	159,291	3,635	90.44	13.97	5.0	18,604
Total Summer Season, 1933	10,829	1,166,452	32,548	251.18	363.60	74.31	416,146
,, ,, ,, 1932	10,131	1,115,650	28,441	203.16	350.14	66.17	359,117
,, ,, ,, 1931	10,269	1,166,605	22,366	227.55	404.62	55.74	309,834
,, ,, ,, 1930	9,318	1,004,380	18,213	159.09	318.11	51.6	245,825

United States of America

1933 *Statistics*

American operated airlines (domestic and foreign extensions) carried 568,940 passengers during the calendar year 1933, compared with 540,681 in the previous year, according to the Department of Commerce. Air express also increased appreciably during 1933, while air mail was slightly less than in 1932. There were 504 airplanes in operation on scheduled airlines at the end of the year. These aircraft consumed 26,326,796 gallons of gasoline and 924,411 gallons of oil during 1933. The airlines furnished employment for 6,273 persons, classified as follows:—543 pilots; 206 co-pilots; 2,320 mechanics and ground crew men; 1,854 other hangar and field personnel; 1,370 operation and office personnel.

Comparisons of operation by American operated airlines (domestic and foreign extensions) in the calendar years 1933 and 1932 follow:—

	1933.	1932.	% increase 1933 over 1932.
Domestic.			
Miles flown	48,771,553	45,606,354	6.9
Passengers carried ...	493,141	474,279	4.0
Express (pounds) ...	1,510,215	1,033,970	46.0
Mail (pounds)	7,362,180	7,393,257	*0.4
Mail payments	$16,467,215 (£3,384,138)	$19,294,332 (£3,965,132)	*14.6
Passenger miles flown ...	173,492,119	127,038,798	36.5
Foreign Extensions.			
Miles flown	5,870,992	5,326,613	10.2
Passengers carried ...	75,799	66,402	14.1
Express (pounds) ...	942,597	566,851	66.3
Mail (pounds)	454,352	515,466	*11.8
Mail payments	$6,946,474 (£1,427,555)	$6,939,989 (£1,426,221)	0.09
Passenger miles flown ...	25,307,960	19,513,789	29.7
Domestic and Foreign Extensions.			
Miles flown	54,642,545	50,932,967	7.3
Passengers carried ...	568,940	540,681	5.2
Express (pounds) ...	2,452,812	1,600,821	53.2
Mail (pounds)	7,816,532	7,908,723	*1.1
Mail payments	$23,413,690 (£4,811,692)	$26,234,321 (£5,391,353)	*10.8
Passenger miles flown ...	198,800,079	146,552,587	35.6

* Decrease.

Air passengers were paying for transportation at an average rate of 6.1 cents (3d.) a mile on domestic air lines at the close of 1933, the report states. They made flights averaging 367 miles (591 km.) in length. The domestic lines has 102,544 flights scheduled during the year and completed 97,978, fulfilling 95 per cent. of their schedule.—*Wall Street Journal*, 10/3/34.

Mail Carried in 1933

	Miles of Service. Scheduled.	Actually flown.	Total weight of mail dispatched. (pounds).	Average compensation per mile flown. 1932. $	1933. $
American Airways—					
1. Boston-New York ...	335,849	270,881	89,350	0.49	0.39
2. Chicago-Memphis ...	611,226	563,413	61,299	0.56	0.40
20. New York-Fort Worth	2,885,701	2,628,846	394,165	0.55	0.45
21. Dallas-Galveston ...	236,088	224,983	29,239	0.49	0.50
22. Dallas-Brownsville ...	402,751	392,072	85,426	0.54	0.44
23. Atlanta-New Orleans ...	313,716	307,588	64,025	0.46	0.47
24. Chicago-Cincinnati ...	428,882	390,638	66,143	0.50	0.36
27. Bay City-Chicago ...	1,493,326	1,303,347	132,524	0.43	0.41
29. New Orleans-Houston ...	235,908	234,497	33,852	0.46	0.47
30. Omaha-Atlanta Pt. I ...	1,156,119	1,066,757	161,008	0.52	0.43
33. Atlanta-Los Angeles Pt. I	3,063,428	2,992,493	345,684	0.64	0.46
Total	11,162,994	10,375,515	1,462,715	0.56	0.44
United Air Lines—					
3. Chicago-Dallas ...	1,815,734	1,721,742	363,021	0.57	0.45
5. Salt Lake City-Seattle ...	1,242,887	1,202,654	229,328	0.60	0.46
8. Seattle-San Diego ...	1,892,902	1,824,918	389,396	0.55	0.45
17. New York-Chicago ...	2,795,033	2,537,242	1,062,737	0.56	0.35
18. Chicago-San Francisco	5,075,457	4,878,906	1,109,525	0.67	0.45
30. Omaha-Kansas City Pt. III	108,648	107,012	20,862	—	0.48
Total	12,930,661	12,272,474	3,174,869	0.61	0.44
Western Air Express—					
4. Salt Lake City-San Diego	1,045,087	1,024,877	191,502	0.51	0.50
12. Cheyenne-Albuquerque-Amarillo	569,846	547,864	107,298	0.51	0.41
33. Albuquerque-El Paso Pt. II	109,890	107,892	7,933	0.63	0.39
Total	1,724,823	1,680,633	306,733	0.52	0.46
Transcontinental and Western Air—					
34. New York-Los Angeles-San Francisco ...	6,511,464	6,180,378	1,114,496	0.70	0.44
Eastern Air Transport—					
19. New York-Miami ...	3,089,923	2,985,263	646,951	0.49	0.44
New York-Atlanta ...	524,970	493,484	136,037	—	0.35
Atlanta-Jacksonville ...	103,976	102,201	10,528	—	0.24
Total	3,718,869	3,580,948	793,516	0.49	0.42

	Miles of Service. Scheduled.	Miles of Service. Actually flown.	Total weight of mail dispatched. (pounds)	Average compensation per mile flown. 1932 $	Average compensation per mile flown. 1933. $
Northwest Airways—					
9. Chicago-Pembina Pt. I	1,700,081	1,622,911	229,326	0.55	0.45
Kohler—					
9. Milwaukee-Detroit Pt. II	298,218	269,187	14,250	—	0.35
Pennsylvania Air Lines—					
11. Washington-Cleveland ..	950,247	802,757	195,149	0.40	0.39
National Parks Airways—					
26. Great Falls-Salt Lake City	737,916	723,843	53,491	0.48	0.39
United States Airways—					
30. Kansas City-Denver Pt. II	401,024	394,231	18,326	0.32	0.34
Total	40,136,297	37,902,622	7,362,872	0.57	0.435

Par rate of exchange $1 = 4s. 1d.

Aviation, March, 1934.

China

Air Transport in China

The organisation and development of rail and air transport in China during the last 25 years has met with many difficulties, owing to the unstable political situation. Up to 1930 there was no question of regular air transport in China although the Ministry of Communications established an air mail service between Shanghai and Nankin in 1929. In 1929 the China National Aviation Corporation was formed, partly with Chinese Government capital and partly with American capital, furnished by China Airways Federal Inc. U.S.A., a subsidiary of Pan-American Airways. This company operated an air mail service between Shanghai and Hankow (840 km.) (522 miles) with Loening Amphibians.

In 1930 the (New) China National Aviation Corporation was formed and the services operated with the support of the Ministry of Communications and of China Airways were combined. The China National Aviation Corporation has a capital of 10 million Mexican dollars (£645,161), the holding of the Chinese Ministry of Communications being 55 per cent. and of China Airways (*i.e.*, Pan-American Airways) 45 per cent. The head office of the C.N.A.C. is at Shanghai, the directors are Chinese, but the air traffic management is in American hands and all pilots and the chief technical personnel are Americans. A number of Chinese are being trained and act as second pilot. By the terms of the agreement between the Chinese Government and the C.N.A.C. this company is bound to employ Chinese personnel, when adequately trained.

The Eurasia Aviation Corporation, Peking, was established in February, 1930, by the Chinese Government (share of capital 2 million Mexican dollars (£129,032)), and the Deutsche Luft Hansa (share of capital 1 million Mexican dollars (£64,516)). The company's directors are German and Chinese. The air traffic management and the pilots are German, but a certain number of Chinese pilots are to be employed eventually.

The services operated by the C.N.A.C. and the Eurasia are so distributed that the companies are in no way rivals. The object of the Eurasia is to establish an airway between the chief towns in China and Europe, via Siberia, whilst that of the C.N.A.C. is the organisation of internal air transport, hence the Eurasia is only allowed to operate any internal services which do not detrimentally affect the interests of the C.N.A.C. Significant of conditions in China is the

fact that the Ministry of Transport has officially and strictly forbidden either company to carry non-paying passengers.

The C.N.A.C. operates a service from Shanghai westwards along the valley of the Yang Tse Kiang, via Nanking to Hankow (840 km., 522 miles), daily, Mondays excepted, the distance being covered in 6½ hours. The fare from Shanghai to Hankow is (Mexican) $200 (£13). Twice a week the service is extended from Hankow to Chungking, 800 km. (497 miles), up river, the distance being covered in 6½ hours. Fare (Mexican) $300 (£19). From 11th November, 1933, the line was extended from Chungking to Chengtu, 265 km. (165 miles), to the N.W., and plans exist for an extension to Yunnanfu, 600 km. (373 miles), to the S.W. in the province of Yunnan. Loening Amphibian aeroplanes, with accommodation for four passengers, fitted with a Pratt and Whitney 500 h.p. engine, are used for the above services. The C.N.A.C. owns seven of these machines. The journey from Shanghai to Chengtu takes three weeks by ordinary transport and three days by air, *i.e.*, a saving of 19 days.

In a northerly direction the C.N.A.C., since 10th January, 1933, has maintained a service from Shanghai to Peiping, via Haichow, Tsingtao and Tientsin. The distance Shanghai—Peiping (1,170 km., 726 miles) is flown in 8½ hours; the passenger fare is $220 (£14). For this service Stinson landplanes, 250 h.p. Wright Whirlwind engine, with accommodation for four passengers, are used.

The following C.N.A.C. transport statistics are given, though they cannot be regarded as absolutely reliable:—

1930 (Oct./Dec.) ...	3,008 passengers	22,000 kg. (21.65 tons)	mails and freight.
1931	2,296 ,,	34,500 kg. (33.96 tons)	,, ,,
1932	3,153 ,,	31,000 kg. (30.51 tons)	,, ,,
1933 (Jan./Nov.) ...	2,349 ,,	40,767 kg. (40.12 tons)	,, ,,

The regularity in 1932 was 98 per cent.

Hawaii

Annual Report of the Inter-Island Airways, Ltd., for the year ending December 31st, 1933

The following has been extracted for the 1933 Annual Report of the Inter-Island Airways, Ltd.:—

Operation.—While the number of passengers carried during the first six months of 1933 totalled 2,588, or 27 per cent. less than the same period the preceding year, it is gratifying to report that during the latter part of the year there was a noticeable increase in passenger travel, and this, together with the eruption of Mokuaweoweo on the summit of Launa Loa, increased our total number of passengers carried to 6,868, or only 2.6 per cent. less than carried in 1932. Revenue, however, for the year decreased 7.8 per cent., or from $138,584.83 (£28,480) to $127,809.91 (£26,269).

Mileage flown in 1933 was 221,520 miles, which brought our total since inauguration to 1,029,670 miles and total flying time to 10,818 hours. During this period we have carried 39,150 passengers without casualty of any kind to passengers or personnel. Strict maintenance of equipment, combined with extreme caution exercised by our operating personnel, is responsible for our fine record to date.

Net loss from operation in 1933 was $7,988.83 (£1,642) against $13,431.00 (£2,760) in 1932. Income, however, from interest and dividends amounting to $10,491.23 (£2,156), turned this loss into a net income for the year of $2,502.40 (£514), against a net loss in 1932 of $8,355.83 (£1,717). Final annual adjustments and charges resulted in our closing the year with a deficit of $429.69 (£88).

REGULAR AIR TRANSPORT COMPANIES IN EUROPE

Return showing Details of Fleets in Operation as at 31st December, 1933

SUMMARY.

Country.	Total No. of Civil Aircraft on register of Country.	REGULAR AIR TRANSPORT. Operating Company.	Total No. of aircraft in operation.	Total available pay load (lbs.)	Average available pay load per aircraft (lbs.)	Total H.P. of fleet.	Average H.P. per aircraft.	Average available pay load (lbs.) per H.P.	Total mileage of routes operated, 1933.	Scheduled weekly mileage, 1933.	Average scheduled weekly mileage per aircraft, 1933
Great Britain	1,055	I.A.L.	23*	113,665	4,942.0	39,040	1,696.1	2.9	13,709	64,560	2,807
Austria	57	O.L.A.G.	10	13,368	1,336.8	5,425	542.5	2.5	2,313	13,194	1,319
Belgium (inc. Congo) ...	173	S.A.B.E.N.A.	31	63,755	2,056.6	20,310	655.1	3.1	3,032	23,578	761
Czechoslovakia ...	130	C.S.A.	13	25,520	1,963.1	6,690	514.6	3.8	1,037	9,500	731
		C.L.S.	14	25,783	1,841.6	8,280	591.4	3.1	1,421	15,990	1,142
		Total	27	51,303	1,900.1	14,970	554.4	3.4	2,458	25,490	944
Denmark	11	D.D.L.	5	9,510	1,902.0	2,895	579.0	3.3	860	8,608	1,722
Finland	17	Aero O/Y	4	7,540	1,885.0	3,175	793.7	2.4	991	10,606	2,451
France	1,654	Air France	134*	237,232	1,770.4	91,075	679.7	2.6	21,450	130,670	975
Germany	1,072	Deruluft	11	19,915	1,810.5	7,950	722.7	2.5	1,703	28,429	2,583
		D.V.	16	15,900	993.7	2,400	150.0	6.6	896	12,035	752
		D.L.H.	145	278,361	1,919.5	90,290	622.1	3.1	21,597	161,950	1,117
		Total	172	314,176	1,826.6	100,640	585.1	3.1	25,196	202,414	1,176
Greece	—	S.H.C.A.	4	9,176	2,294.0	3,670	917.5	2.5	460	5,520	1,380
Hungary	—	Malert	6	15,045	2,507.5	4,050	675.0	3.7	767	6,180	1,030
Italy	393	S.A.A.L.I.	7	13,330	1,904.3	5,430	775.7	2.5	861	14,780	2,111
		S.A.N.A.	16	37,191	2,324.4	20,000	1,250.0	1.9	1,697	14,686	918
		S.I.S.A.	11	18,000	1,636.4	7,900	718.2	2.3	953	11,580	1,053
		S.A.M.	31	55,604	1,793.7	24,110	777.7	2.3	3,944	26,872	867
		S.A.A.E.I.	8	16,400	2,050.0	7,200	900.0	2.3	1,221	5,098	637
		S.A.N.A.A.	4	8,800	2,200.0	3,360	840.0	2.6	830	3,980	995
		Total	77	149,325	1,939.3	68,000	883.1	2.2	9,506	75,996	987
Netherlands	67	K.L.M.	34	86,315	2,538.7	32,435	954.0	2.7	11,360	53,020	1,559
		K.N.I.L.M.	8	20,370	2,546.2	6,630	828.8	3.1	1,865	10,944	1,368
		Total	42	106,685	2,540.1	39,065	930.1	2.7	13,225	63,964	1,523
Poland	141	L.O.T.	34	52,120	1,532.9	14,340	421.8	3.6	2,841	26,950	792
Roumania†	41	L.A.R.E.S.	8	9,220	1,152.5	3,210	401.2	2.9	702	6,534	817
Spain	96	L.A.P.E.	10	20,760	2,076.0	8,305	830.5	2.5	571	7,994	799
Sweden	26	A.B.A.	5	10,473	2,094.6	4,180	836.0	2.5	1,156	11,086	2,217
Switzerland	82	Swissair	12	21,325	1,777.1	8,105	675.4	2.6	2,464	19,866	1,656
		Alpar	3	3,358	1,119.3	630	210.0	5.3	374	6,084	2,028
		Total	15	24,683	1,645.5	8,735	582.3	2.8	2,838	25,950	1,730
Yugo-Slavia	9	Aeroput	9	6,856	761.9	3,265	361.7	2.1	949	8,274	919

* Does not include Aircraft in reserve or used for special charter work.

† Details as at 31/12/1932.

Brazil

Summary of Civil Aviation Statistics, 1928-1933

	1928.	1929.	1930.	1931.	1932.	1933.
Number of Air Transport Companies	3	4	4	4	4	5
Total Length of Km. ...	6,595	7,245	15,503	16,374	18,355	20,066
Routes Operated Miles ...	4,098	4,502	9,633	10,174	11,405	12,468
Number of Aircraft Employed	57	51	62	66	55	54
Number of Pilots Employed	24	23	39	27	34	40
Number of Flights ...	1,178	1,476	1,767	1,746	1,683	2,599
Distance Flown, Km. ...	912,359	1,140,130	1,707,977	1,854,696	2,200,446	2,444,853
Miles ...	566,914	708,446	1,061,287	1,152,456	1,367,297	1,519,160
Flying Hours	6,615	8,212	12,013	12,097	14,187	15,341
Number of Passengers Carried	2,504	3,651	4,667	5,102	8,894	12,750
Weight of Mail, etc., Tons	9.53	23.67	31.44	47.15	57.13	73.87
Weight of Baggage, Tons	19.94	29.15	23.49	45.88	100.37	142.78
Weight of Goods, Tons ...	1.88	7.66	9.46	21.57	127.82	110.97

REVIEWS

Electrical and Wireless Equipment of Aircraft

By S. G. Wybrow. Published by Pitman. Price 6/-.

This book belongs to the series of text books for ground engineers, published by Pitmans, and deals with the numerous electrical mechanisms used in aircraft. It is almost a text book on electricity, for Mr. Wybrow explains the modern theory of electrical currents in the first chapter, and devotes the second to a discussion of all the necessary electrical units. These chapters are well done, considering the limited space, and those who study them carefully will have a knowledge of fundamentals which will help them to understand the rest of the work. The reading matter would look less formidable if it were cut up into more paragraphs.

Chapter III discusses magnetism, with the appropriate units, and is followed by an excellent chapter on secondary cells, in which the nickel iron nickel cadmium types are described, as well as the usual lead cell. He then deals with electrical wiring in detail, and follows with a chapter on magnetos, and the book is completed with two chapters on wireless.

This book should fulfil its purpose thoroughly. Mr. Wybrow is full of knowledge on this branch of aircraft work, and his many practical notes are most useful. The work can be thoroughly recommended to ground engineers, and also to pilots and others who wish to know more about the electrical equipment of aircraft.

Foretold

By " Streamline." Published by Eneas Mackay. 3/6.

This book contains a number of short stories of " second sight," several of which are concerned with aircraft. They are stated to be true by the author on the authority of some unknown informants, but the names of the people and places referred to are fictitious. This procedure, which appears to be normal with books dealing with such matters, entirely prevents any check on the accuracy of the descriptions and completely deprives the work of any interest to those who may desire to test the possibility of such things happening. But it may be that I am taking it too seriously and that it is merely an addition to sensational literature.

The dust-cover carries a sketch showing a fight between a modern fighter aeroplane and a German scout of the type used in the late war. Naturally, the German is falling in flames, which appear to have started immediately from all parts of the machine, including the wing tips. This incongruous illustration is possibly a suitable introduction to the stories in the book, which latter I found extremely boring, though it is possible that they may have an appeal for those who like this type of literature.

Winged Victory

By V. M. Yeates. Published by Jonathan Cape. Price 10/6.

This book contains a narrative of supposed events in various Air Force units in France during the Great War and is full of descriptions of fights in the air, tempered with accounts of what are usually known as " binges " in the mess and elsewhere. There is no real plot, and the real interest of the work

is contained in the author's attempt to analyse the effect of war strain on an average Englishman. The loss of friends, the strain of waiting for machines that are overdue, the pure excitement of a fight, and the nerve-strain resulting, especially when the hero has got himself into an extremely dangerous position, are well told.

The result of living in this way leads men to seek any means of relieving their minds, of killing even momentarily their memory of things that have happened, and the only available method is by means of alcohol. This chemical, taken in excess, only aggravates the trouble that it was intended to cure, and the result to the victim is a nervous breakdown. Whether the advantages given by alcohol balance the disadvantages, or whether the eventual breakdown would come sooner without drink than with it, is a question probably unsolved.

Those who wish, for professional reasons, to get a direct insight into war flying will find more of interest to them in the Official History than here; but there must be many who desire some information on this subject and who would like it served up with scraps of conversation and intimate details about the participants. These latter will find this book to their taste.

Engineering Drawing Practice

The Institution of Engineers, Australia. Price 4s. 6d.

This book is an attempt at the standardisation of the methods and symbols used in the making of engineering drawings. It is an extension of a previous work, published in 1926, which is stated to have had a wide sale.

The work deals with its subject matter in considerable detail. There are five pages devoted to the size of drawings alone, while four pages are used in describing how to fold these drawings when they are made. It is difficult to remember anything which has not been dealt with, but the general conclusion is that the drawings produced by any well-organised engineering firm in this country are reasonably in accordance with the standards laid down. This, in itself, makes the book of considerable value, not only for educational purposes in the case of junior draughtsmen, but also as a work of reference for their seniors when something has to be put on a drawing which is outside the previous experience of the firm.

The important feature of any engineering drawing is that it should describe the article it deals with in such a way that there is no excuse whatever for the shop making a mistake. This matter concerns not only dimensions, but also such processes as heat treatment, type of finish, and also the precise materials which are to be used. But if a firm is too individual in its methods of using symbols, it will find that men newly taken on will have a lot to learn, and, in consequence, will be liable to make a number of mistakes. However well the older men may understand the symbols used, a short and lucid description is often to be preferred to the symbol, unless the latter is in common use and is also so often required that its meaning is not likely to be forgotten. In this connection it would be interesting to know how many firms dealing with structural engineering use the complete list of symbols given here for various methods of riveting. There are actually over one hundred, and the memorising of these would be difficult; while a reference by the worker to a separate document for the meaning of any symbol is a process which loses time. This type of memory feat is undesirable and is also liable to lead to errors by those who believe their memory to be more accurate than it really is.

The book is one which should be welcomed by all those interested in engineering work, especially in the drawing office and the shops. It contains much interesting material and should help towards the bringing of the drawings of different firms into closer unison.

Lightning and Aircraft

By G. C. Simpson, F.R.S. London: Meteorological Office, Professional Notes No. 66. H.M.S.O. Price 4d. net.

There is always some electrical force in the earth's atmosphere, especially near the surface, and the first part of this paper describes the electrical effects which may be expected to accompany various types of weather. The generation of lightning and the ways in which the presence of aircraft may influence an electric discharge are then discussed and, lastly, the dangers to and the measures of protection that can be adopted for aeroplanes, airships and kite balloons, are considered separately. The general conclusion is that "on aeroplanes without aerials there is practically no danger to the personnel, . . . the position, however, is much more serious if the machine has a trailing aerial. . . . The most important thing, therefore, to be done when it is known that the plane is in a danger area or is about to enter a danger area is to withdraw the aerial." Even though not actually struck, an aeroplane, including metal parts not connected by conductors, may collect charges able to give unpleasant though not dangerous shocks.

No authentic case is on record of an aeroplane having been wrecked as the result of being struck by lightning and since January, 1925, when the first report of a British aeroplane being struck by lightning was made, only ten cases have been reported. A short account of each of these occurrences is given in the first appendix, and a second appendix contains the report of the committee which examined the problem of the protection of R.101 from the risks of lightning.

Flying Memories

By S. O. Bradshaw. Published by John Hamilton, Ltd. Price 7/6.

This book depends for its appeal on its illustrations as the reading matter is limited to descriptive matter. These illustrations portray incidents concerning aircraft from the war period to recent times; there is one showing the Heyford Bomber.

They are reproduced, apparently, from wash drawings and are generally accurate illustrations of the machines, though the artist occasionally shows that tendency to elongate the fuselages in the way that is met with in early French drawings of aircraft. It is noticeable that the later drawings in the book are considerably better than the earlier ones. They differ considerably in quality, the best being, probably, an illustration of a Hawker Demon taking off, while some of them are distinctly poor.

All the drawings in the book are in monochrome. This is a considerable handicap to an artist, as there are few subjects for the brush which lose so much as aircraft when they are divorced from colour. Mr. Bradshaw can draw aeroplanes well, and we hope to see further examples of his work done under conditions of freedom from the limitations of monochrome illustration.

Days on the Wing

By Major the Chevalier W. Coppens de Houthulst, D.S.O., M.C., etc. Translated by A. J. Install. Published by John Hamilton, Limited. Price 10/6.

The author of this book is known already throughout the world as a gallant war pilot. We now learn that, in addition, he is a man who cannot only write, but write well, and that he possesses the eye of a novelist for a dramatic situation and the skill to describe it.

His book differs from the usual book of this type. We do not get the ordinary accounts of mess binges alternated with accounts of air fights, most of which are very much like each other, but a calm and collected account of a career told with a sense of humour and skill in the use of words.

Conditions in the Belgian Air Force during the War seem to have been very different from those in our own. If every English officer who expressed forcibly his criticisms of the particular aeroplane he was detailed to fly had been sent to the trenches the Royal Air Force would soon have been left with no pilots at all; but this seems to have been the penalty enforced against Belgian pilots in such cases. The fact that the criticism was in many cases justified seems to have been regarded rather as an aggravation of the offence. The general temperament of the war pilot seems to have been much the same in all the armies and excess spirits often expressed themselves in rags which are similar to those which happened in many R.A.F. messes. But it is not likely that any English mess ever went so far as to persuade a commanding officer to turn out a whole squadron for inspection in anticipation of a bogus visit from the king, managing somehow to get away with it afterwards by tampering with the staff of the local telephone exchange.

As a reviewer who has grown blasé with this type of War literature, I can say that it is much the best of the books of this class that I have ever read, and I wish there were more like it. A word of praise is due to Mr. Install for an excellent translation and for a number of notes which will be found instructive by the uninitiated.

Le Vol Vertical

By Lieut.-Colonel Lamé. Published by Ed. Blondel, La Rougery, Paris. Price 45 Francs.

This book consists of a history of flying machines of the helicopter type, from the earliest days to the present time, and it also contains a section on the mathematical theory of these machines.

The helicopter, as a type, has always attracted the attention of inventors and was, in fact, one of the first schemes suggested for producing a heavier-than-air machine for aerial navigation. The great advantage it possesses is the possibility of vertical flight and the idea of being able to land and get off from one's own back garden has appealed to many of those interested in aeronautics, and does still appeal to many members of the general public. Actually, there is no difficulty whatever in producing a machine of this type which can lift itself off the ground; such machines have frequently been produced by inventors, but it is other matters which have always proved to be stumbling blocks, such as stability, ability to alight safely in case of motor failures, and the difficulty of propelling the machine horizontally at a speed comparable to that of an ordinary aeroplane.

But it is always possible that some unknown inventor will solve these difficulties and will produce something possessing the advantages of the helicopter principle, combined with the vital advantages possessed at present only by the aeroplane. If and when this happens the dreams of Colonel Lamé will come true and we shall be able to dispense with our present enormous aviation grounds and do all our flying from areas not much exceeding the roof of an ordinary house. Touring in the air will be much more pleasant than now, as we should be able, as the author states, to stand still in the air to admire a pleasant view, or to approach near the earth to examine something which had attracted our attention.

Advantages such as these are of considerable value, and it is for that reason that a book such as this is to be welcomed.

Colonel Lamé starts his book by giving a resumé of the older history of helicopters, in which he mentions the designs of several well known Englishmen, such as Sir George Cayley, but he is in error in supposing Sir Charles Parsons' experiments to have been made in America. They were made in England. He follows this by a section on the mathematics of these machines in which there is a noticeable absence of any reference to vortex theory. He then proceeds to

describe, with illustrations, the more modern machines of this type, including a captive helicopter which, it will be news to many, was devised in Austria during the war as a substitute for the kite balloon, with the assistance of Professor von Kàrmàn. This particular machine still seems to hold the helicopter performance record by lifting some 4,500lbs. to a height of 50 metres and it was stabilised by a system of three cables attached to different parts of the apparatus.

But it must be confessed that none of the machines illustrated here show the least promise of being the ideal flying machine of the future, unless it is the autogiro, which does not conform to the definition of a helicopter. The problem is therefore still open to an inventor of real genius.

The book is well written and well illustrated, and it is to the general good that we should be reminded occasionally of the advantages that a really successful helicopter would possess and also of the progress that has been made. Colonel Lamé's book is an important addition to the aeronautical library.

The History of British Aviation

By R. Dallas Brett. Published by John Hamilton, Ltd. Price 21/-.

This book owes its inception to the author having been presented with some pre-war volumes of *Flight*. Being struck with the many notable feats performed by pre-war pilots, he decided to write this history in order that these things may be better known to those who fly to-day.

The book is therefore a sort of synopsis of the contents of *Flight* from 1908 to 1914 with a few additions from Royal Aero Club records. As such it is accurate in its information, but gives rather a cold and colourless account of what happened, the impression left on one's mind being that one has been reading an old almanack. Had the author consulted other papers and other documents, he would have learnt much about pre-war aviation that would have illuminated many of his descriptions, for, excellent as is the *Flight* account of these matters, it is impossible that one paper can contain all that may be said about everything.

It does not appear that the author was connected with aviation in the early days, or knew any of those who were connected with it, as the book lacks completely that personal touch, which can only come from personal knowledge of individuals, and which is the sole advantage of a history written soon after the events described, before they can be looked at in perspective.

Notwithstanding these points, the book has certain advantages. It is accurate and it is written in a style which makes it easy to read. It is full of excellent photographs and drawings, also abstracted from *Flight*, and the printing and general get up is excellent. Those of us who knew many of the people referred to here, knew how they worked, their difficulties and the results they obtained with their primitive aeroplanes and engines, and the almost complete ignorance of the modern pilot of the tribulations of the pioneers, without whom the modern aeroplane could not have existed, will hope that this book has a ready sale. There is much that happened in the old days which should not be forgotten.

CORRESPONDENCE

To the Editor of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

In re Wilbur Wright Lecture

Dear Sir,—As one who was able to join in the chorus of congratulations to Professor Melvill Jones on his delivery of the Wilbur Wright Lecture on the 31st May last, may I be allowed to add one or two remarks on the subject matter?

Three forms of discontinuity or stalling were shown. There is yet a fourth; this takes place over the centre of certain sections as, for example, double sections or sections with " wash-out " trailing edges.

The cinema made very living, by means of smoke jets, the flow of air over aerofoils, which is best seen, however, in the laboratory and which, I think I am right in stating, were first shown by a series of photographs in the AERONAUTICAL JOURNAL, Volume XIV, October, 1910, and Volume XIII, October, 1909.

These photographs, showing various forms of " surfaces of discontinuity," or more colloquially, " stalling," were the result of a series of experiments made by me which led to my discovery of the use of " rider " planes or " slots " and their later developments, *i.e.*, the automatically opening slot and rotating " riders " or rotors, as set forth respectively in the following journals:—

Flight.

November 20th, 1914	... ...	pages 1134-1136
September 13th, 1928	... ...	,, 782-784
June 20th, 1930	... ...	page 668
July 18th, 1930	... ...	,, 820

The Aeroplane.

July 16th, 1930	... ...	page 202
September 24th, 1930	... ...	pages 718-722

The Aeronautical Journal.

Volume XXXIV	... ...	pages 682-683
,, XXXIV	... ...	,, 839-844
,, XXXV	... ...	,, 113-115
,, XXXVI	... ...	,, 332-334

The connection that I wish to draw between this Wilbur Wright Lecture and the publications quoted is this:—The lecture demonstrated that " the alternations of the flow between the two (front) forms (of discontinuity) are very rapid when thought of in terms of measurement of forces on a small model, but they are surprisingly slow in terms of the distance travelled by the aerofoil through the air. Either kind of flow can and generally does persist when the aerofoil travels through a distance of twenty or more times the length of its chord."

It is this time element which enables rotor rider planes to exercise such outstandingly stabilising effects and also to provide a maximum amount of control over a wider range than the slot, or slot and ailerons. (See AERONAUTICAL JOURNAL, January, 1934, pages 59 to 65, and February, 1934, pages 138 to 161.)

The reason appears to be that while it is true that time is taken to change from one form of flow to another, it is equally true that time is taken to change from a steady to a turbulent or discontinuous flow or vice-versa. However, the passage of a moving plane over the surface of a stalled aerofoil cuts through the eddies and ensures a steady flow which " persists " for a time. If the moving plane travels again over the surface before incipient turbulence again sets up, the flow continues to remain steady. These moving rider planes may conveniently take the form of rotors which sweep out a " living slot " on aeroplanes or " surfaces of revolution " over the noses of aircraft provided with air-cooled engines.

Yours faithfully,
A. P. THURSTON.

11th June, 1934.

The 577th Lecture read before the Royal Aeronautical Society since its foundation, January 12th, 1866.

THE ROYAL AERONAUTICAL SOCIETY

A meeting of the Royal Aeronautical Society was held in the Lecture Theatre of the Royal Society of Arts, at 18, John Street, Adelphi, London, W.C.2, on Thursday, April 26th, 1934, when a paper by Dr. R. Stüssel, of the Deutsche Lufthansa, on "The Problem of Landing Commercial Aircraft in Fog," was read and discussed.

Mr. H. E. Wimperis (Director of Scientific Research, Air Ministry, and Member of Council) in the chair.

The CHAIRMAN: The Society was indeed fortunate in having the opportunity to welcome Dr. Stüssel and in having secured a paper by him, because he was in charge of research and development work in connection with the Lufthansa machines and their instruments and was in a very good position indeed to be able to say how his company considered that this immensely difficult problem should be solved. Even surface craft—railway trains, motor cars, ships, etc.—were enormously handicapped by fog, and, in spite of their long experience, those responsible for these services had not solved the problem of successful operation in fog; it was "one up" to the aeronautical world that it had even tackled the problem; if these earlier forms of transport had to operate at a minimum speed of 60 m.p.h., as had the aeroplane, one may doubt whether those responsible would have attempted to solve the problem.

Dr. Stüssel addressed the meeting briefly, speaking in German, and asked Mr. Low to present the paper on his behalf.

THE PROBLEM OF LANDING COMMERCIAL AIRCRAFT IN FOG *

BY

DR. R. STÜSSEL

Summary

(1) Survey of the present methods of carrying out air transport service when visibility is bad.
(2) What is essentially required of technical aids for landing under bad weather conditions.
(3) Short survey of current German methods for solving the problem of landing in fog.

The necessity for being able to carry out air transport unhindered by weather conditions is inseparably associated with the idea of commercial air service. This great problem of "flight in any weather" has confronted us since the inception of regular services between places having corresponding traffic needs, that is to say, since the very birth of air transport.

* Translated from the German text.

Just as in practical experience far distant goals are generally attained by pressing forward step by step, stubbornly and indefatigably, so with this great problem of flight in bad weather; the solution will be reached only by obtaining with logical accuracy greater or smaller partial solutions which can be obtained at any time. The question now under discussion—of landing in fog—regarded from this point of view—is only a partial problem (although perhaps the last and most difficult) of the entire problem of flight in bad weather. For a comprehensive treatment of the question of landing in fog it therefore appears to be absolutely necessary first of all to explain the present position of the entire problem of carrying out air transport when visibility is bad, and determining what progress has been made towards the solution of the partial problems in practical air transport.

The first problem which, in carrying out air transport, is eliminated from the whole problem of " flying in fog " is the necessity of being able to fly (with due safety) through *local* fog which tends to prevent the flight being carried out. A brief explanation must be given of the technical devices used for solving this problem.

The introduction of the turn indicator for rendering it possible to fly in a straight line when visibility is nil, is a first and perhaps a particularly important step. It has taken many years to develop this instrument until it was fully fit for service, and its use has now been adopted in all countries to such an extent that it is now counted among the indispensable components of the commercial aeroplane. Independently of this, efforts are being made to perfect speedometers, altimeters and climbing speed indicators, and render them serviceable for blind flying. A thing requiring particular care in this connection also is the magnetic compass, whose pendulously suspended magnet system makes it very difficult to obtain constantly satisfactory and easily read indications of direction when flying in bad weather. Aircraft crews place great confidence in all these instruments which are of fundamental importance for flying in bad weather, in spite of many failures which occurred when they were first introduced, and in spite of their faults of which the crews are aware. The defects hitherto associated with these bad weather instruments have been eliminated to such an extent that commercial flights can be carried out through local fog zones.

The work of development in this sphere has, however, already passed beyond this first stage. Work is being carried out with a view to the introduction of apparatus for further simplifying and facilitating flight in fog. In order to relieve the crew during blind flights of long duration, in addition to the turn indicator there is used increasingly and with good results the gyroscopic apparatus for transverse and longitudinal position, which has recently been very considerably improved. It is well known that these devices are of limited reliability, due to the principle on which they are based. An attempt is made to remedy the defects associated with the magnetic compass by the additional use of gyroscopic apparatus which indicate a direction, once set, although only for a limited time, namely, the so-called directional gyroscope. The supplementing of the barometric altimeter by an apparatus which indicates directly the height above the ground at a given time, is a question which has been zealously studied for a long time. Furthermore, hard work is being directed towards evolving a suitable combination of several indicating apparata in order to simplify the reading. Finally, in this connection mention must be made of the efforts to introduce automatic steering apparatus for one or more control surfaces. All this work for further facilitating and simplifying flight in bad weather has already progressed so far that tangible results gained in practical use are already available or may soon be expected.

A further preliminary condition which is absolutely essential in order that flights may be carried out through local fog zones, is the possibility of communication between the aircraft and the ground stations for the exchange of weather

reports or other important messages. The triumphal progress of wireless telegraphy in connection with aerial navigation is too well known for it to be necessary to dwell on the development of wireless instruments. For some considerable time all the aircraft of the Deutsche Lufthansa have been provided with wireless apparatus, which show very high and quite satisfactory reliability in operation. Wireless apparatus now belongs to the standard equipment of a commercial aeroplane (Fig. 1).

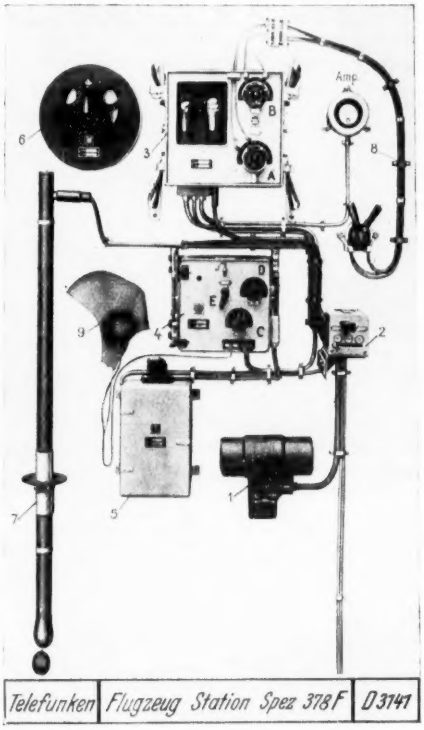


FIG. 1.

View of the construction of the long-wave W/T apparatus used by the Deutsche Lufthansa.

(1) *Transformer for anode voltage of the transmitter;* (2) *Key with switch;* (3) *Transmitter;* (4) *Receiver;* (5) *Anode battery of the receiver;* (6) *Antennæ reel;* (7) *Antennæ shaft;* (8) *Bowden wire for use with transmitter;* (9) *Cap head-piece with earphones.*

Direction finding by wireless telegraphy, which is the most important aid to flying in fog zones, very soon arrived at a high state of efficiency with the introduction of radio apparatus. The extraordinarily good and reliable operation of the ground organisation in international European air services provided for this wireless direction finding, particularly in consideration of the system of radio bearings from ground stations generally in force in Europe, that is to say,

the individual treatment of each separate aircraft by the ground direction finding radio station, is a very gratifying and hopeful example presaging successful international co-operation. A troublesome feature, however, is the uncertainty inseparable from wireless direction finding in the twilight and during the night. In England this twilight and night effect has been combated particularly successfully by the introduction of the Adcock antennæ. This problem is also being attacked vigorously in other countries. It is to be hoped that we shall soon be well equipped to deal with this situation. In order to give an idea as to the extent to which these direction finding ground stations have been introduced, some figures from the records of the Deutsche Lufthansa are classified in the following tables.

SUMMARY REGARDING RADIO DIRECTION FINDING IN THE OPERATION OF THE DEUTSCHE LUFTHANSA DURING THE YEARS 1929 TO 1933.

Year.	Total number of required bearings.	Station bearings.	Destination and course bearings.	Operation hours for one bearing.
1929 ...	1,610	1,035	575	11
1930 ...	3,113	1,640	1,473	7·5
1931 ...	8,758	2,641	6,117	4
1932 ...	17,195	2,727	14,468	2·5
1933 ...	32,550	2,999	29,551	1·5

Apart from this very efficient direction finding ground station service, efforts are being made to effect further improvements in carrying out direction finding service by the introduction of wireless direction finding apparatus carried on the aircraft. Thus the crews become more independent in their navigational measures and more independent of the wireless information service, which is often very much in demand. In this connection particular mention should perhaps be made of a wireless destination finding apparatus recently produced by the firm " Telefunken," which is operated in a very simple manner when steering towards the port of destination (Fig. 2).

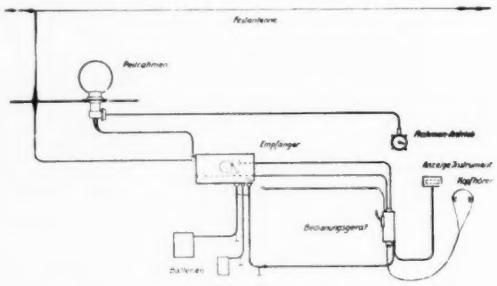


FIG. 2.

Diagrammatic representation of the construction of a terminal aerodrome W/T direction finding apparatus of the Telefunken firm.

The use and operation of all these technical aids must be made as easy as possible for the crew of the aircraft if they are to be of real service in increasing safety in flight through fog zones. The arrangement of the apparatus in the pilot's cockpit in such a manner that the corresponding indicators can be easily read by anyone of the crew, and the controls can be used without trouble, is a problem that is studied very carefully from all sides. The experiences of the Deutsche Lufthansa have lead to a unification which is illustrated in the photograph of the pilot's cockpit of a Junkers Ju 52 (Fig. 3).

A further very important factor in working for the safety of flight through local fog zones is the need for instructing the crew in the use of the instruments and in direction finding. This expedient also is now resorted to by almost all countries with good results. With regard to the Deutsche Lufthansa the first preliminary attempts were made to give the crew instruction in the use of the instruments, back as far as 1925 and 1926. Since 1928 systematic instruction has been given to all members of the crew for which particularly the winter months were used. In view of the important frictionless co-operation of the crews with the ground personnel, in recent years station superintendents and the personnel of the direction finding ground stations have also taken part in this "course for flying in fog." The following tables show the extent these winter courses of instruction have attained in recent years.

FIG. 3.

Pilot's cockpit of the three-engined express commercial aeroplane of the Deutsche Lufthansa. Reading from the right hand of the bottom line, right to left round the photograph, the arrows point to: Remote control for W/T transmitter, W/T receiver, magnet switch, fire-extinguishing cocks, land-light switch, switches for tele-compass and time indicator, first pilot's seat, rudder control bar, port control column, compass, circuit breaking switch, transmitter for tele-compass, coarse altimeter, fine altimeter, time indicator, speed indicator, indicating apparatus (tele-compass), variometer, gas lever, gyro-apparatus, collector switch for magnetos, instrument board watch, atmospheric thermometer, revolution counter, antennæ ampèremeter, tele-thermometer, indicating apparatus for tele-compass, monometer, W/T key, starboard control column, antennæ reel, second pilot's seat.

SYNOPSIS RELATING TO THE COURSES OF INSTRUCTION IN FLIGHT IN FOG, ARRANGED BY THE DEUTSCHE LUFTHANSA DURING THE YEARS 1930-1934.

	Winter, 1931-32.	Winter, 1932-33.	Winter, 1933-34.
Pilots	60	123	134
Aircraft wireless operators and mechanics	—	92	—
Station superintendents	34	60	96
Ground wireless operators	—	—	51
Total	94	275	281

All the auxiliary instruments mentioned above have already reached a high stage of efficiency and are used in great numbers by air transport companies. An essential condition for their successful use is, however—and this must be emphasised—the provision of an aircraft suitable in respect of reliability, aerodynamical characteristics, for flying in bad weather. In view of the great progress recently made in the construction of aircraft and aero engines, this requirement also can be fulfilled to a very great extent.

In flight in bad weather the aeroplanes by no means meet essential requirements in one respect, namely, in weather conditions which cause ice to form on the aeroplane. With the increase of bad weather flights during the winter, difficulties due to the formation of ice on the aeroplane also increased in like proportion. No completely satisfactory results have been obtained by any of the measures hitherto employed against this serious danger, such as treating the surface with chemical agents, protecting the front edges of the most important parts of the aeroplane with mechanically operating "ice removers," heating these parts with hot air, or the use of indicators for avoiding zones in which there is danger of the formation of ice on the aeroplane. The possibility of carrying out flights in fog is limited by weather conditions under which a coating of ice is formed on the aeroplanes.

This limitation which is imposed on the carrying out of flights through local bad weather zones by weather conditions, involving the danger of the formation of a coating of ice on the aeroplane, is the only serious limitation. Moreover, to recapitulate, the necessary technical auxiliary devices to enable flights to be carried out through local fog zones with safety and according to plan, are available quantities, or, as in the case of accuracy in direction finding in twilight and by night, there are excellent prospects of these problems being solved in the near future. Further, it is already true that in many commercial air transport concerns, technical auxiliary devices are being investigated and introduced which more than fulfil the bare requirements in respect of safety and accuracy, and constitute very important refinements of the auxiliary devices for flight in bad weather.

It is difficult to ascertain the numbers of such flights through local fog zones carried out in the European commercial air service. I would attempt to give an idea by citing the result of a thorough perusal of the wireless log given in figures. The total number of flights during the winter months of 1933-34 on some of the particularly notoriously difficult scheduled routes, undertaken by the Deutsche Lufthansa, have been closely investigated by means of the wireless logs. At the same time, careful note was made as to which flight, according to the entries in the log, was carried out involving a passage through a fog zone on any part of the route and with the use of the auxiliary devices for flight through fog. The routes selected:—The night mail route Berlin—Cologne—London, which, for the first time, was run in winter as a night service; the Alpine route Munich—Venice; and the very difficult day mail service Vienna—Salonica. The result is shown in the following table:—

SURVEY RELATING TO THE PROPORTION OF BAD WEATHER FLIGHTS OF THE TOTAL FLIGHTS CARRIED OUT ON CERTAIN NOTORIOUSLY DIFFICULT ROUTES OF THE DEUTSCHE LUFTHANSA DURING THE MONTHS OCTOBER, 1933—FEBRUARY, 1934.

Route.	Oct., 1933. %	Nov., 1933. %	Dec., 1933. %	Jan., 1934. %	Feb., 1934. %
Night (Post and Freight)— Berlin—Cologne—London ...	46	70	80	57	48
Day (Passengers)— Munich—Venice	55	80	92	40	42
Day (Post and Freight)— Vienna—Salonica	50	62	100	63	75

The above figures were obtained by thorough examination of the wireless logs in question. In so doing, the only cases considered were those in which bad weather conditions were clearly recorded. *Thus the values mentioned are in each case the minimum.*

In spite of a certain discrimination which such a method of estimating involves, the figures give a very impressive picture. In one case the number of flights carried out in bad weather was 100 per cent. of the total flights. It should be especially noted that the weather conditions during this winter were extraordinarily unfavourable, and the month of December must be regarded as abnormally bad.

The regularity achieved on this route under difficult conditions should, in this connection, be of interest and provide a criterion by which to judge the result which can be obtained by the use of auxiliary measures. The following table gives details of the flights which could not be continued to their destinations by reason of bad weather:—

SURVEY REGARDING THE PROPORTION OF SCHEDULED FLIGHTS WHICH WERE NOT CARRIED OUT ON CERTAIN NOTORIOUSLY DIFFICULT ROUTES OF THE DEUTSCHE LUFTHANSA DURING THE MONTHS OF OCTOBER, 1933, TO FEBRUARY, 1934.

(All flights in which the prescribed destination was not reached are shown as flights not carried out.)

Route.	Oct., 1933. %	Nov., 1933. %	Dec., 1933. %	Jan., 1934. %	Feb., 1934. %
Night (Post and Freight)—					
Berlin—Cologne—London ...	13·5	15·3	37·5	11·5	12·5
Day (Passengers)—					
Munich—Venice	1·9	3·8	12·5	3·9	0
Day (Post and Freight)—					
Vienna—Salonica	0	0	10	0	0

It will be seen that on the very difficult night routes in the winter service, in spite of the number of flights carried out through fog, a certain number of flights had to be abandoned, particularly in December; but on the whole the regularity attained under these difficult conditions, on the night mail route and also on the Alpine route and the Vienna—Salonica route, was very gratifying.

In flying through local bad weather zones, it has fortunately been possible for some considerable time to avoid serious accidents and personal injuries in the entire service of the Lufthansa. However, several cases in which very considerable damage to materials was involved occurred during the winter service. All this damage was caused by the aeroplane becoming very extensively and suddenly coated with ice, thereby causing a forced landing. In one case an aeroplane which had reached its destination after a long night flight, in attempting to descend from an altitude of 1,800m. through a cloud layer with a view to landing, was forced to the ground in a few minutes due to a coating of ice having been formed on the aeroplane. Breakdowns in service were also caused in certain cases by the uncertainty in wireless direction finding, mentioned above, in the twilight and by night.

Even at a time when flights could not be carried out with the desired reliability on account of local bad weather zones en route a further problem arose, namely, that of carrying out flights when bad weather prevailed at the port of departure; that is to say, the necessity of starting in a bad-weather zone. Thus, in several respects, more is demanded of the technical auxiliary devices.

All apparatus for the supervision of the position of flight, that is to say the speedometer, climbing-speed indicator and also the turn indicator and further additional gyroscopic apparatus, must give reliable readings from the very start. Moreover, it is absolutely essential that there should be good possibility of control

of all the instruments, including the wireless apparatus, before the take-off. This requirement is easily fulfilled by the selection of sources of energy which are independent of the relative wind, that is to say by the use of the electrical system on the aircraft or the suction air of the engine.

The measurement of altitude is a particularly important point in connection with starts made in bad weather. During the entire process of taking-off it is necessary to observe the distance from the ground very exactly. Although in quite a general sense it is very desirable to have an instrument for measuring the distance from the ground which works independently of air pressure, it was found that, for this case, it is possible to manage to a very great extent with a sensitive and reliable barometric altimeter which is adjusted before the start to the air pressure prevailing on the ground. A particularly unpleasant feature is, however, the pressure variations which may occur in the pilot's cockpit due to the effect of the relative wind. It is necessary to eliminate this cause of error by utilisation of the static pressure for measuring altitude.

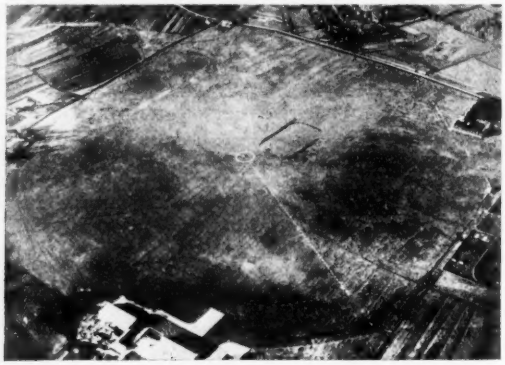


FIG. 4.

Air photograph of an airport with marked line for bad weather take-off. The location of the starting point on the marked line is indicated by a connecting line with the customs' office.

Most difficulty has been experienced in maintaining the desired direction when the take-off is made in bad weather. At present there are available on board, as auxiliary devices, the compass and the turn indicator, which are supplemented, if necessary, by optical observations on the ground from which the take-off is made. In bad weather in which the obstacles surrounding the port are hidden by clouds, but in which satisfactory visibility still prevails on the ground—that is to say when the height of the clouds is about 40-50m.—it is, of course, easily possible to maintain the direction or take-off by using the auxiliary devices provided. But as soon as any considerable lack of visibility occurs on the ground, that is to say particularly in the case of ground mist or dense driving snow, then it is advisable to use other auxiliary devices.

At present there are used, for instance, lines extending about 300 m. along the runway produced by the direct application of coloured material on the ground in the form of a strip or by lamps let into the ground (Fig. 4). Such auxiliary devices appear to satisfy requirements. But it is certainly very desirable if, in the case of arrangements to be provided for assisting landings in bad weather, provisions can likewise be made, if possible, without additional special costs, for further auxiliary devices for maintaining the take-off direction.

It should be self evident that the use of an aeroplane offering maximum reliability and good climbing powers is an essential condition for starts made in fog. In this case the climbing power should be so calculated that all obstructions in the vicinity of the port can be easily flown over, and it should not be necessary to keep to a definite course for starting through a zone of obstructions.

From what has already been said, it will be seen that a start can be made in foggy weather safely and at scheduled time of departure by means of the technical auxiliary devices now available, but when visibility is bad on the ground, particular value must be attached to auxiliary devices for maintaining the start direction. It is to be regretted that no figures are available relating to the carrying out of starts in foggy weather by the machines of the " Lufthansa." Naturally, a large number of flights were started when clouds were low. As, however, such flights are nowadays hardly considered to be particularly difficult, no entries concerning them were made in the wireless logs. Starts during poor visibility on the ground have likewise been carried out for some considerable time. Particularly when the scheduled time for departure is fixed in the early hours of the morning, it is very frequently necessary to make such starts in poor visibility in consequence of great banks of ground fog. This is also not regarded as very difficult. In any case, it may be said that foggy conditions at the port of departure very rarely prevent a flight from being carried out.

It has been extremely rarely that serious difficulties have occurred in making such starts in the Deutsche Lufthansa service. In recent years there have been only two cases in which material damage was caused by faulty starts during poor visibility. In one case the aeroplane, when visibility was poor, on taking off on a snow-covered ground swerved and got damaged. In another case, starting in driving snow, great quantities of snow were accumulated on the wings which apparently influenced the starting properties of the aeroplane to such an extent that it was impossible to avoid collision with an obstruction.

The solution of the great problem in connection with air traffic " Flight in any weather " has been reached by systematic tackling of one partial problem after another. This way is necessary in order to benefit continually by practical experience in the construction of technical auxiliary devices, and thus serious technical mistakes can be avoided. The problem of landing in fog is the last link in the chain. Nevertheless, it was not possible to postpone all treatment of this question until the above partial problems were completely solved. On the contrary, it will be understood that, besides the work connected with increasing the safety of flight through local fog zones and starting in fog, certain measures for carrying out landing in fog were made to meet all cases in which such landings must be made owing to the unforeseen advent of bad weather. It is also clear that such measures are provisional and will be replaced as soon as possible by more perfect technical expedients. I am of the opinion that all devices and measures at present introduced in European air transport for landing in fog must be regarded from this standpoint. Moreover, in the use of these devices very valuable experience has been gained, which will be of great assistance for the construction of technical auxiliary devices, when finally evolved.

In discussing these devices for landing in fog now used in European air transport, I should like to limit myself to the so-called " ZZ " process usually employed by the Deutsche Lufthansa, as this should give a good idea of the present position of the question of landing in bad weather under practical working conditions.

The degree of bad visibility, that is to say the height of the clouds, and the kind and size of the obstructions in the vicinity of the port are very important considerations in the carrying out of landing in bad weather. The station superintendent should, in each particular case, according to weather conditions, investigate whether the landing is still possible by a shortened bad weather process,

whether the state of affairs necessitates the use of the " ZZ " process, or whether the landing should be attempted at all owing to excessively low visability, or rather be made at another port.

The first case occurs when the clouds are sufficiently clear of the obstructions to aircraft around the port, in order to allow the aeroplane to pass through the clouds and land without danger. An aeroplane which, in order to avoid flight near the ground, approaches the port flying blind, is conducted to the port by wireless direction finding by the ground stations, and, as soon as approach is detected by wireless or by hearing, is given instructions to pass through the clouds and to land.

If the obstructions around the port protrude into the clouds so that the approach for landing must be carried out with very poor visibility, the aeroplane approaching the port is informed that the landing will be carried out in accordance with the " ZZ " process. To these instructions there are added at once information regarding the height of the barometer on the ground for correcting the altimeter, and information regarding the wireless station sector in which the approach for landing should be made. The wireless station sectors are the most favourable air corridors selected and fixed for each port in consideration of the obstructions and the prevailing directions of the wind. Two such zones are generally sufficient for each port.

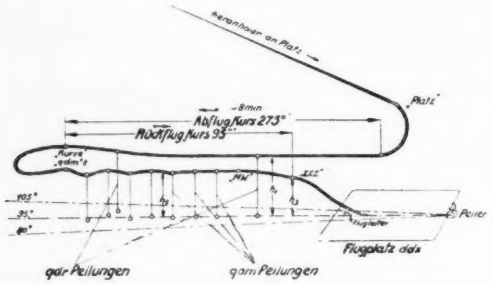


FIG. 5.

Diagrammatic representation of the carrying out of a bad weather landing by the " ZZ " process.

For carrying out the landing, the aeroplane is first of all communicated with at a sufficient height by wireless by the ground stations and is conducted to the port. It is ascertained by ear from the ground when the aeroplane is flying over the port, and this fact is communicated to the aeroplane. When the aeroplane receives this information it moves away in the direction from which the approach for landing should be made. The determination of this direction can be facilitated by directions transmitted by wireless. After flying for about eight minutes the aeroplane is turned in order to approach the port, and after starting the approach requires wireless instructions about every minute for correcting the compass course. At the same time the altitude of flight is gradually decreased to such an extent that the aeroplane can start to land on reaching the boundary of the airport. The station superintendent will carefully follow the approach flight in co-operation with the ground wireless station. Important information regarding the course of flight is communicated in certain recognised abbreviations. Finally, when it has been ascertained beyond doubt that the aeroplane is on the correct course for the approach flight, the signal to land is given by means of the Morse letters " ZZ " (Fig. 5).

It is clear that this process makes great demands on the ability of the personnel—the station superintendent and the wireless operators and the crew—

and requires the very careful co-operation of all concerned. Faults in the technical auxiliary devices must be made good by personal performance. These are the characteristic features of a provisional process arising out of the necessity for dealing with unforeseen landings in bad weather, whereby an attempt is made to make some progress in the question of landing in bad weather.

The imperfections are to be found, first of all, in determining the direction for shaping the course of flight through the zone of obstructions. The crew must—by means of compass readings and certain wireless directions, while considering the wind drift—conduct the aeroplane through the zone of approach to the port, which is a very difficult task with the wind velocity changing with the altitude.

The pilot determines the distance from the airport by observing the duration of flight, and is assisted by the ground personnel by aural and visual observations. It is here that faulty observations can be made by the crew, owing to changing directions and the varying force of the wind, and by the ground personnel owing to faulty observations due to noise interference.

The height above the ground, which, together with the distance from the port, is of importance for passing into a glide, is ascertained by barometric measurements. Here also there is room for improvement.

The difficulties by no means end with those cited, the number of them is determined by the character of the process. The drawbacks have become very noticeable in certain cases in practical application. But the successful assistance given in very many cases to the crew by the introduction of the measures included in the " ZZ " process, and the possibility of collecting practical experience and thus getting nearer a solution of the problem, by far outweighs these drawbacks.

This process is very much used in the Deutsche Lufthansa service, particularly on difficult routes. The wireless logs give very clear information on this point. For the three particularly difficult routes of the " Lufthansa " already mentioned in similar connection, the corresponding figures are given in the following table.

SURVEY RELATING TO THE NUMBER OF THE LANDINGS IN BAD WEATHER CARRIED OUT WITH THE ASSISTANCE OF THE " ZZ " PROCESS, ON CERTAIN NOTORIOUSLY DIFFICULT ROUTES OF THE DEUTSCHE LUFTHANSA DURING THE PERIOD OCTOBER, 1933—FEBRUARY, 1934.

Route.	Oct., 1933.	Nov., 1933.	Dec., 1933.	Jan., 1934.	Feb., 1934.
Night (Post and Freight)—					
Berlin—Cologne—London ...	6	12	15	10	5
Day (Passengers)—					
Munich—Venice	–	–	2	2	1
Day (Post and Freight)—					
Vienna—Salonica	1	3	2	1	–

It is at once seen that on the night mail route very many landings were made with the assistance of the " ZZ " process. This is partly explained by the very frequent occurrence of fog banks in the early hours of the morning. Another reason, however, is the very unpleasant phenomena associated with all night flights, namely that details regarding atmospheric conditions cannot be estimated too well at night, and unforeseen weather conditions occur with great frequency. In any case, the importance already attached to landing in bad weather in commercial aviation can be clearly seen.

The safety with which the landings are carried out in accordance with this process is naturally due to the fact that it is an improvised process which is very dependent on the degree of bad weather conditions. Landings through layers of clouds at a height of 80 to 100m. are carried out with satisfactory reliability. It lies in the nature of this improvised process evolved for use in emergency, that, in the event of unforeseen bad weather, it is of necessity employed under extremely difficult conditions. In such cases when this method

has to be employed its imperfections are naturally much in evidence. Certain landings which had of necessity to be carried out under such difficult conditions have, consequently, led to material damage. Thus in one case a night mail aeroplane on the route London—Berlin was surprised by a sudden morning fog and was forced to land at Tempelhof under very difficult conditions. In an attempt to fly through the approach corridor on the correct course, the aeroplane, for reasons not quite explained, got out of its course and came into contact with the wireless tower of the Berlin radio transmitter. In spite of the collision, the aeroplane was still capable of flight, but had to make a forced landing in the vicinity owing to the severe damage it had suffered. This accident clearly illustrates the difficulty in keeping to the course in flying through the approach corridor. In another case in which, for quite similar reasons, a landing had to be made at the Cologne airport while flying blind, although the aeroplane passed safely through the zone of approach, it came to earth some distance before reaching the airport, which clearly shows the urgent need for supplying the pilot with reliable information regarding the distance from the port.

Although any interruption in service must be regarded as a serious matter, it must however be said that, in the interest of progress, it cannot be entirely avoided. It is important, however, that the knowledge gained from such incidents should be utilised as soon as possible for the improvement of the auxiliary devices.

The present position of the whole problem of carrying out commercial flights when visibility is bad can be summed up briefly in a few sentences.

Flight through local bad weather zones on the route can be carried out to a very great extent with sufficient safety with the aeronautical material, instruments, and devices which are at present available. The problem of flights under weather conditions in which a coating of ice is formed on the aeroplane is still unsolved. Wireless navigation often suffers from the uncertainty of direction finding in the twilight and by night. Every effort is being made to improve further the technical auxiliary devices.

The start under bad weather conditions is likewise carried out to a very great extent and with a high degree of safety. Improvement of the instruments is desirable.

Owing to unexpected changes in the weather, it is frequently necessary to carry out landings in bad weather conditions. With this end in view, provisional measures have been introduced which are employed to a very great extent in the Deutsche Lufthansa service in the interest of safety of flight through bad weather. These measures make very great demands on the technical auxiliary devices available, and also on the personnel. At the present position of the problem of flight through bad weather, the early introduction of carefully-developed devices to assist landing in bad weather is urgently needed.

II. Owing to the great attention that is already being paid to the question of landing in bad weather by the commercial air lines, a great amount of experience has been accumulated. Hence result a number of fundamental requirements which should be fulfilled by the technical auxiliary devices for assisting landing in bad weather conditions, and it would appear to be well worth while to deal with them in detail. In order to avoid misunderstanding it should be pointed out that bad weather conditions is meant to include, as usual, all kinds of weather conditions which render it difficult to effect a landing, that is to say, also conditions in which, owing to very low cloud layers, buildings, or other obstructions at the airport are entirely or partially hidden, and also the much more difficult weather conditions in which the whole of the landing process must be carried out while flying blind. The requirements of the technical auxiliary devices in the case of landings through low cloud layers are naturally less than those in the case of a landing carried out while flying blind. Fundamentally, however, they bear the same relation to the entire problem.

For carrying out landings in bad weather, a few particularly favourably-situated approach corridors are used by the commercial air lines in the different airports. The selection is made on the basis of practical experience, due consideration being paid to the obstructions situated around the airport and the most frequent directions of the wind. Two, or at the most three, such approach zones are sufficient for any port. The breadth of the approach zones varies within wide limits. At certain ports they have to be limited to relatively small zones. Thus the chief problem in landing in bad weather for commercial aircraft is to fly through the approach zone which is most favourable in each particular case, while in this zone to pass the obstructions around the port, and at the same time to reduce the altitude of flight so that after crossing the boundaries of the airport the landing can be made (Fig. 6).

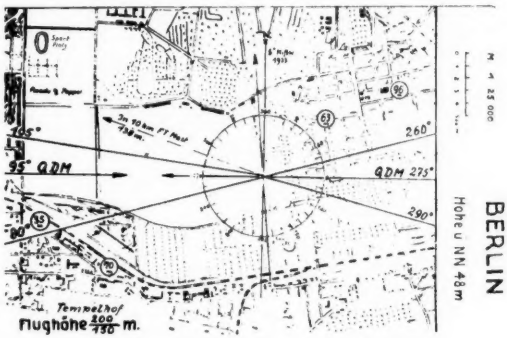


FIG. 6.

Sketch of the Tempelhof airport, Berlin, showing the zones of entry and the minimum height to be maintained. Similar diagrams of all German airports are available for the use of pilots.

A solution for this comprehensive problem is best gained in practice by gradually solving the partial problems one by one. Three such separate problems are, on further consideration, eliminated from the entire question. Technical auxiliary devices are necessary:—

(*a*) For determining the direction of flight.
(*b*) For determining the distance from the airport.
(*c*) For determining the altitude of flight.

Reliable information relating to these three questions form the basis for carrying out landing in bad weather.

In examining the qualities demanded in particular of the technical auxiliary devices for the solution of these three problems, one arrives first of all at two fundamental observations, which apply in the same way to all auxiliary devices.

(1) As in the landing process we are concerned with a flight in the vicinity of obstacles, the technical auxiliary devices must afford immediate indications in each particular case. Deviations from the correct course of flight should immediately be brought to the notice of the pilot. Thus the only methods that can be recommended are those which render it possible for the pilot himself to read the indications while in his cockpit. Processes in which computations made on the ground are transmitted to the aeroplane should be avoided.

(2) In view of the existing conditions, special demands are made on the technical information and the possibility of checking it by comparison with some

other satisfactory indications. It is very important that all false indications which cannot be checked by the crew should be eliminated. Methods in which, owing to technical imperfections, false information which cannot be checked is given, do not fulfil the requirements. Processes in which technical imperfections are notified as such, if necessary by a complete cessation of indication, appear to be particularly suitable.

The technical auxiliary devices for *determining the direction of flight* during the landing, deserve to be discussed first of all, because experience has shown that their introduction is a matter of great urgency and would result in considerable progress towards a practical solution of the question of landing in bad weather.

The auxiliary means now used for determining the direction of flight, essentially certain wireless directions sent by the ground stations and the information supplied by the compass provided on board the aeroplane, are suitable for navigation en route, but are fundamentally insufficient when the aeroplane is approaching the airport and is passing the zone of obstructions. Difficulties in keeping the course could be considerably reduced by the introduction of directional gyroscopes or other like instruments. But the necessity of taking into consideration the wind drift in each case in fixing the course, involves inaccuracies which are not compatible with accurate orientation. Moreover, the bearings obtained on the ground and communicated to the aeroplane by wireless are inadequate and should be avoided for the reasons already mentioned.

A very important question in the selection of technical auxiliary devices for determining the direction of flight is whether information regarding the direction to a point located at the port is sufficient, or whether beyond this the course of flight should be designated. The fixing of the direction to a point situated at the port would ensure arrival at the point, but the course of flight traversed would depend on the starting point of the approach flight and the deflection due to wind. After the previous discussion regarding the carrying out of the flight through the zone of obstructions it will be understood that this determination of direction to a point situated at the port is not sufficient; but it is necessary to use methods which supply the pilot with information as to how best to maintain a certain course of flight.

The necessity for rendering it possible for the pilot to read continuously the data necessary for maintaining the course of flight will be quite clear after what has been already explained. The marking of certain definite points on the course of flight is insufficient.

The length—necessary for practical reasons—of the course of flight easily recognised in the horizontals is likewise of importance for development of the methods. This length should not be too short, in order that it be reasonably possible for the pilot, before passing the zone of obstructions and before beginning the landing, to shape his exact course of flight. With the provisional landing process now employed, an approach flight lasting eight minutes has been found to be satisfactory. This time could perhaps be shortened owing to the increased ease in assuming the line of approach. In any case, in consideration of the increasing speed of aeroplanes, it may be advisable to accept 30-40 km. as the desirable length of the approach flight.

The lateral divergence of the path of flight recognisable on board, in spite of the limitation due to spatial conditions, should not be too small, as otherwise aerodynamical difficulties may arise. Particularly when the course of flight is broadened from the port as angular sector, with the small choice of the angle, the approach flight may be difficult in the vicinity of the port owing to overcontrolling the aeroplane. The selection of a suitable, numerically-determined measure depends to a great extent on the method selected and the local conditions, and must be left for practical tests.

In addition to the questions already discussed relating to determining the direction of flight, according to recently gained experience it is of the greatest importance that the pilot should be *directly aware of his distance* from the airport in the vicinity. With the provisional processes now employed, this information is obtained by the pilot observing the time of flight and by aural and visual observations on the ground. When the weather conditions are not too unfavourable, the pilot obtains valuable assistance in this way. But the carrying out of landings in bad weather is rendered very much more difficult by the imperfection of this auxiliary means and is limited to conditions which are not too severe.

The determination of distance is of importance for maintaining the altitude of flight necessary at the time, and for the beginning of the gliding flight prior to landing. The possibility of obtaining information regarding distance continuously is very convenient for the landing process but not absolutely necessary. According to recent experience, it appears to be sufficient if certain points in the course of approach, the distance of which from the port is very well defined, are made recognisable to the pilot.

Nothing definite can yet be said regarding the number and position of these distance marks on the course of flight. Two points appear to be particularly important, namely:—

1. The point at which a reduction in the altitude of flight maintained during the approach flight is begun, that is to say the change from the approach flight into gliding flight.
2. The point at which the aeroplane changes from gliding flight into the actual landing, that is to say in the immediate vicinity of the landing ground.

The distance of the point at which the aeroplane passes into gliding flight depends on the altitude necessary for the approach flight and on local conditions. The distance should generally be about 3km. The second point likewise depends very much on local conditions—a few hundred metres from the port, or even directly at the boundary of the landing ground. It should be repeated that this information regarding the selection of suitable distances should be supplemented by practical experience.

In each particular case, the extent in respect of length and breadth in which these points must be made recognisable to the pilot on the course of flight also needs careful consideration. The breadth depends on the spatial characteristics of the course of flight fired in the horizontals and the dimensions should be such that it insures all possible paths of flight being included. The longitudinal divergence must render possible a sufficient time for recognition in the aeroplane; five seconds should be the minimum.

Care must also be taken to ensure satisfactory distinctive marks for the various distance-points. It is necessary for the pilot to recognise at once over which point he is flying. A general arrangement for the distinguishing features of the distance-points which can be observed by optical or acoustic means would be necessary.

The third factor in carrying out landings in bad weather is the altitude of flight. The importance of this information for carrying out a landing safely in bad weather is by no means less than that of the other two factors already discussed. By the constant improvement of the barometric altimeter, however, a technical auxiliary device has been produced which is now used very extensively for assisting landings in bad weather. It is also permissible gradually to increase the demands for accuracy because, in practical application, it is only after experience that one proceeds to particularly difficult landings while flying blind. For these reasons, the measures for the introduction of completely satisfactory technical auxiliary devices for determining altitude of flight, may, in respect of urgency, be ranked below those already discussed.

The information regarding altitude of flight is necessary in order that in the whole process the aeroplane may keep a suitable distance from the obstructions and in order that it may begin the gliding flight so that on reaching the airport it can proceed to land. Thus there is needed:—

(1) The actual distance from the ground with its obstructions, that is to say the height over the ground; and

(2) The actual height over the port.

As in many cases, the two measurements of height do not quite agree, it would therefore be advisable to make two supplementary height measurements in the case of a landing in bad weather—namely, a measurement of the distance from the ground and a measurement of the height over the airport.

It is easily possible to effect a simplification, when the necessary distance from the obstructions is maintained, by the minimum altitude of flight for the approach flight and gliding flight being fixed in each particular case and by the aeroplane being provided with reliable auxiliary devices for ascertaining this minimum height over the airport which is to be maintained. The Deutsche Lufthansa, for the carrying out of landings according to the provisional process with the use of barometric altimeters, has fixed and made known the minimum altitude of flight to be maintained over the different ports and approach zones, according to local conditions.

The extent of the scope of measurement in which the determining of an altitude of flight for a port must be possible, depends upon the minimum altitude of flight during the approach flight. According to experience gained by the Deutsche Lufthansa on German airports, this figure is generally 200-250m. In the case of certain ports with unfavourable ground conditions, a minimum height of 400m. must be prescribed for the approach zones selected.

The question whether the barometric altimeter, after suitable development, could satisfy the requirements mentioned herein for landing in bad weather, is such an obvious one that we shall deal with it briefly. The readings given by this instrument, after the usual adjustment to the air pressure prevailing at the port, are the actual heights over the airport, that is to say, the desired data for the landing. Regarded from this standpoint, such instruments are fundamentally suitable. They are, however, not so favourable in respect of the necessary reliability and accuracy. Several sources of error are possible.

Experience has shown that the air pressure prevailing at the airport can be determined and communicated to the aeroplane very exactly, but mistakes are liable to occur. The inaccuracies which occur with every barometric measurement of height due to variation of the actual distribution of pressure at various altitudes can be disregarded in view of the inconsiderable heights in question. In consequence of the extraordinary technical progress, the mechanical faults associated with this instrument are very slight. At the worst, variations may occur due to the influence of the air current on the air pressure used for measuring the height. Unless certain precautions are taken, these errors may become quite considerable (50 metres or more). It is therefore necessary to utilise static pressure for measuring height in landing in bad weather. A certain unreliability of measurement is due to the possible inadequacy and interruption of this communication of pressure to the measuring instrument.

After all, therefore, the barometric devices for measuring height during a landing in bad weather can be used with good results. As, however, in this method of measuring it is not impossible for uncontrollable faults to creep in, it is advisable for the readings to be supplemented by further information.

The fundamental considerations regarding the carrying out of landing in bad weather are clearly the outcome of practical experience in flying in bad weather—as has already been shown. They are an illustration of the latest position with regard to the entire problem of "Flight in any weather," and they will have a

determining influence on further progress towards the solution of the problem of landing in bad weather. They are consequently fully applicable to the conditions prevailing in European commercial aviation. This fact is perhaps of importance in judging the question as to what extent these considerations can have general application independently to the type of port. Although experience seems to show that they can be applied extensively, varying local conditions render other considerations necessary.

III. The problem of landing in bad weather has been regarded from the standpoint of commercial aviation specialists. I have endeavoured to obtain a small survey of the troubles and necessities, results, desires and hopes which are associated with this great problem in commercial aviation. In most countries great energy is now being expended with a view to developing the technical auxiliary devices for solving this problem. An abundance of literature dealing with the means employed and results obtained is available. It is beyond the

FIG. 7.

General view of the Lorenz ultra-short wave beacon for bad weather landings at the Tempelhof Airport, Berlin.

scope of this lecture to review and criticise. I would merely confine myself to completing my statements by giving a brief view of the plans and investigations now being carried into execution in Germany for perfecting the technical devices for assisting landing in bad weather.

The introduction of technical auxiliary devices to render it possible for the pilot to maintain the course of flight in the horizontals has been dealt with as a matter of special urgency for some considerable time. At the instigation of the competent German authorities, the Reichsamt fur Flugsicherung, the firms C. Lorenz A.G. and Telefunken, supported by the Deutschen Versuchsanstalt fur Luftfahrt, have taken up this problem. In 1932 the firm C. Lorenz A.G. produced an ultra-short-wave wireless beacon which was tested in the winter of 1932-33 at the Tempelhof airport by the Deutsche Lufthansa. As a result of the experience thus gained, an improved plant was produced in the autumn of

1933 and put in operation at the Tempelhof airport (Fig. 7). Four aeroplanes of the Deutsche Lufthansa, equipped with suitable receivers, have since tested the usefulness and reliability of the plant in regular service. A plant designed on the same principles by the firm Telefunken will also soon be subjected to a practical test.

Frequent reference has been made recently in technical literature to the form of construction of these plants by the firm of C. Lorenz, so that this point need not be dealt with here. It is a wireless beacon designed in accordance with the guiding ray principle. The guiding ray directed along the approach course can be picked up optically and acoustically in the aeroplane by means of receivers (Fig. 8).

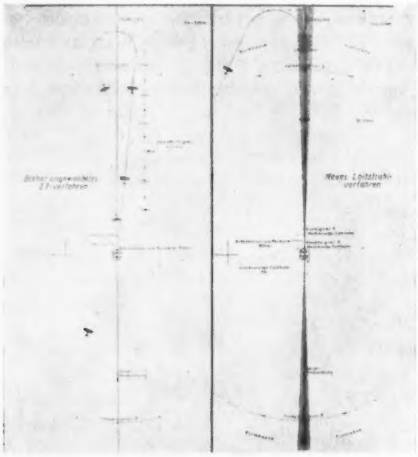


FIG. 8.

Diagrammatic comparison between the "ZZ" process and the new guiding ray process for bad weather landing.

An interesting question is, perhaps, why the use of a wave-length of nine metres was adopted, in spite of the fact that we have very much less experience with this wave-length than, for instance, with the medium wave-lengths of about 800 metres. There were many reasons for this. The ranges of such ultra-short waves can, as experience has shown, be limited to a very great extent, as it appears that disadvantageous reflections from space hardly ever occur. This important property rendered it possible to use, in ports used by commercial planes, wireless beacons of the same wave-length. Transmitter performance and the height of aerial can be kept within reasonable limits. The Tempelhof wireless beacon is one of about 300 Watt, and the height of the aerial is about nine metres. That the wave band below 10 metres is practically free from atmospheric disturbances, is one of great importance in the use of such wireless beacons for landings in bad weather. It is necessary that the wave band selected for such land auxiliary devices should be free from disturbance by other transmitters, and this can easily be effected by use of the wave band selected in this case. Moreover, the selection of such a wave-length, differing considerably from usual lengths, and the consequent necessity of carrying a special receiver, is justified by the fact that for operative reasons the information service must be continued even during the landing for receiving important reports.

The type of receiving apparatus now carried on the aeroplane weighs eight kilos. The receiver is fixed, and can be switched on from the pilot's cockpit at the beginning of the approach flight. The fixed aerial provided on most aeroplanes may be used.

The experience already gained in service is very satisfactory. The apparatus has been subjected to a practical test by various pilots in approximately 700 approach flights. The use of the apparatus will be very much increased in 1934.

At the instigation of the Reichsant fur Flugsicherung, successful investigations have also been carried out in connection with the construction of devices for marking the distance-points in the landing course. The firms Lorenz and Telefunken have produced small ultra-short-wave transmitters (wave-length 9 metres or 50 c. metres) of low output (5 h. 20 Watt) which by way of a small dipole aerial produce sharp pencil rays. The transmitters are modulated as preliminary signal with 1,700 Hz., and as main signal with 700 Hz. The reception in the aeroplane is effected by a very simple and primitive means. On flying over the airport the signals are heard through the guiding ray signals. The first experimental instruments are now being tested at the Tempelhof airport (Fig. 9).

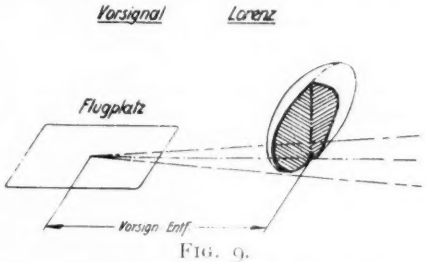


FIG. 9.

Diagrammatic representation of the radiation of a preliminary signal beacon.

It was shown above that the auxiliary devices for maintaining the altitude of flight do not fully satisfy the requirements for landing in bad weather. The Deutsche Versuchsanstalt fur Luftfahrt concerned itself particularly with this problem, and, in collaboration with the firms Lorenz and Telefunken, have proposed a solution which corresponds in principle to the "glide-way process" referred to in American publications, but has been much improved on and adapted to local conditions. The radiation of the guiding-ray transmitter operating on 9 metres, and provided for the approach flight is used, and by means of the 9-metre receiver provided on board, the correct gliding course is ascertained by the use of the lines of constant reception-field strength. Thus, according to this proposal, it is possible to use the glide-way process without any considerable addition to the equipment already provided on board. This process has not yet been tried out on regularly operated air lines. But the tests already carried out have led to very favourable results.

The short survey of the present position of the work of perfecting the auxiliary devices for landing would not be complete without a few final remarks regarding the efforts made to improve the apparatus for direct determination of the actual height of an aeroplane above the ground. For some time much effort has been expended in various countries to solve the problem, but no success has yet been obtained. However, many solutions which seem very promising have been suggested recently. Work is being carried out in Germany, particularly with acoustic devices operating according to the echo principle. In spite of the generally unsatisfactory position of this problem, there is nevertheless reason to hope that a reliable apparatus will be produced before long. Such an apparatus

would give valuable assistance to the auxiliary means for maintaining flying altitude in landing in bad weather.

From what has been said, it will be seen that the important requirement of flight in any weather has already been solved to a great extent. A large number of flights are now being carried out according to time table under difficult weather conditions. The problem of " landing in bad weather " is now the very important question which requires urgent consideration. Provisional measures have been devised for the safety of traffic in cases of emergency. Experience has provided guiding lines for the technical solutions. It is very clear that the work of evolving a final satisfactory device is being carried out with great energy in many quarters. It appears that certain partial solutions will shortly be introduced. This, in my opinion, is the present position of the question of landing in bad weather.

All countries interested in commercial aviation should, I think, co-operate in the effort to solve the problems I have referred to. At this moment it is particularly necessary, in order that the auxiliary devices for landing in bad weather should be constructed on the same principles throughout for the assistance of all European commercial aviation. It is my wish that what I have said may be a small contribution to this common effort.

Discussion

The Chairman: The title, " The Problem of Landing Commercial Aircraft in Fog," did rather less than justice to the width of Dr. Stüssel's communication, for it had dealt also with flying in clouds, flying in bad weather conditions, and landing in those conditions as well as in fog; it contained a very complete account of the work carried out in this connection. The Chairman asked that Dr. Stüssel, when replying to the discussion, would indicate his idea of the difference between " bad weather conditions " and " fog "; so much depended upon the visibility of the ground when a pilot was about to land. Certain fog-landing experiments had been made in this country under very severe conditions indeed, and there was no doubt that in those experiments the pilot could see next to nothing.

The Chairman heartily endorsed the appeal made by Dr. Stüssel at the end of the paper, that all countries should co-operate in the effort to solve the problems under discussion, and said he hoped that Mr. R. S. Capon (the Chairman of the Air Ministry's Fog-Landing Committee) would be able to say something about the corresponding work which had been done in this country. There were questions he would like to put to the representatives of the operating services who were present at the meeting. For instance, if one were landing a machine, either by the " ZZ " or any other method, under conditions of real fog—the kind of fog that they knew so well in London—and if, in the landing run, the path of the machine were indicated by an instrument such as Dr. Stüssel had described, in which a radiation of 9 metres was pushed out in the appropriate direction, and the pilot had to observe an instrument which gave an indication that the machine was flying so as to maintain a constant field strength; were the operating companies content that their machines should be landed under those conditions on the indications of a little needle on an instrument of that kind? Would they say that that was not good enough and that they must have a second indication to provide a check, so that they might not be let down suddenly through an instrument going wrong—for instruments had been known to go wrong! He could understand them adopting the view that even a double check was not so good as landing somewhere else, or, on a persistently foggy route, preferring to use a machine which could be landed safely in any weather—a machine such as the autogiro.

The author's reference to the use of the 9-metre wave length was very interesting indeed, and one of the reasons given for using it was the absence of

atmospherics—disturbances due to weather conditions, thunderstorms and the like, presumably. But nothing had been said about the radiation from the magnetos of motor cars and lorries, and he asked whether Dr. Stüssel had experienced difficulties due to such disturbances.

Mr. R. S. CAPON (Chairman of the Air Ministry's Fog-Landing Committee): He recalled that immediately after the war, when some intrepid individual had suggested trying to find a solution to the problem of landing aeroplanes in fog, some very grandiose schemes had been put forward. One suggestion was to mount a number of airscrews around an aerodrome for the purpose of blowing the fog away; another was to provide coal fires at an aerodrome to warm the air and so cause the fog to dissolve. But neither of these schemes had borne examination. The first operating scheme for landing in fog or in conditions of bad visibility was that described by Dr. Stüssel, and many would appreciate its extreme simplicity in comparison with the earlier ones; though it did not go as far as was intended in the early proposals, it was at least practicable. One of the schemes put forward in the past was that by Professor Lindemann, who had suggested that, inasmuch as a number of fogs were shallow, a solution might be found in a large number of cases by mooring two balloons above the fog, so arranged that the line joining them would be the angle of glide for an incoming aeroplane. The machine would fly up to the first (and higher) balloon and down to the second, and would then continue flying through the fog at the same angle, a device being provided for landing at the end. That scheme had at least the essential quality of simplicity, but it was found that even that was not practicable; the operation was too difficult for the pilot. Ultimately it was decided to use a single balloon, moored above the fog. The pilot was informed of his angle of glide and his course; he would fly to the balloon and assisted by a special gyroscopic instrument he was enabled to descend on the fixed course and at the fixed angle of glide. That had been successful, and several years ago several landings had been made in fog at the Royal Aircraft Establishment. The actual landing was made by means of a device proposed by Mr. Meredith, of the Royal Aircraft Establishment. There was a weight suspended from the machine; when it touched the ground it lit up a red light on the dashboard, and as soon as that light appeared the pilot pulled the stick right back. The speed of descent was so chosen that when the pilot pulled the stick back the machine flattened out just in time for the wheels to make contact with the ground. More than a hundred such landings were made without damage to an aeroplane. The aim in following up the balloon scheme was to test the principle of bringing the aeroplane to a point in space at the boundary of the aerodrome and allowing it to glide from that point to the ground. But they in this country stood alone in advocating that principle; both in America and in Germany, where a great deal of work had been done on fog-landing problems, they preferred to guide the pilot right down to the ground. Here that method had not been favoured because it was thought that difficulties would arise from the number of special instruments and the risks of failure of the instruments; it was considered preferable to bring the pilot to the boundary of the aerodrome and then to allow him to glide the machine in. Experiments had been made to find out what sort of error would occur when a pilot glided a machine from a given point. From 500ft. the error would be of the order of 50 yards on a calm day and 150 yards on a bumpy day; it was felt that that was sufficiently accurate, for seldom would the error be as much as 150 yards.

The logical course of development was followed by replacing the balloon by two radio beacons—a vertical and a horizontal beacon. For the horizontal beacon the equi-signal beacon could be used. For the vertical beacon an aerial which transmitted on a vertical plane was used, and they in common with many other countries had used that method. The pilot flew along the signal beacon until he received the indication from the vertical beacon, and then he descended

on a given compass course and at a given gliding angle until he reached the aerodrome. The radio azimuth was preferred because considerable difficulty was expected in flying along the equi-signal beam, when a pilot had to maintain height, to observe instruments to ensure that he did not get into difficulties, and had also to listen for the marker beacon. He had to make " S " turns to correct the course and he did not know exactly how far he had to turn; he had to proceed on a system of trial and error. The difficulties were not necessarily insuperable, but they were very serious. To obviate some of these difficulties the radio azimuth had been proposed, a directional radio receiver which indicates on the dashboard when the aeroplane is directed towards the beacon so that, assuming no wind, all the pilot has to do is to fly so that the needle is at zero on the indicator scale. In the radio azimuth system the instrument served as a turn indicator as well as a course indicator. One noticed, in communications from the United States, that they were developing a satisfactory radio azimuth scheme there, and there were indications that it was preferred to the signal beacon.

In the United States they had developed the signal beacon, and they had also used, as in the Lorenz system, a landing ray, down which the machines glided. That had the advantage of bringing a machine to any desired point on the aerodrome; but it had also the disadvantage of greater complexity in the instruments and greater risk of failure.

Finally, Mr. Capon said he was particularly interested to note that Dr. Stüssel had stressed the importance of the organisation side of these schemes, and that he was tending to develop first a scheme for landing in conditions of bad visibility rather than in real fog. In attempting a scheme for landing in fog in the first instance one was trying to run before one could walk, and there was no problem in which the " inevitability of gradualness " was greater than in this. They also had come to the conclusion that they must aim first at a scheme which meets conditions of poor visibility only; later, the scheme might be extended to landing in fog.

Captain L. A. Walters (Imperial Airways): In reply to the Chairman's question as to whether the operating companies would be prepared to depend upon the needle of a single instrument for guiding an aeroplane to an aerodrome, he said the only answer was that they must await developments and progress gradually, just as they had progressed gradually to the present stage of efficiency. It had been a matter of trial and error, involving very hard work in grappling with the problems that had arisen and gradually eliminating the various difficulties.

On behalf of his colleagues, Captain Walters tendered to Dr. Stüssel very hearty thanks for his interesting lecture. Dr. Stüssel had indicated very clearly how carefully the ground organisations were thinking out the problems which those in the air had had to contend with. Our pilots had been using the " ZZ " system in the past with a very considerable degree of success; but, as Dr. Stüssel had pointed out, there was room for improvement, because of the considerable possibility of errors from the air side as well as the ground and the instruments used. One looked forward very much indeed to the adoption throughout Europe of some standard method of approaching an aerodrome in fog and darkness, and of landing under these conditions, so that pilots would not have to use a great many different systems as at present.

Major R. H. Mayo (F.R.Ae.S., Member of Council): It was unfortunate that Mr. Woods Humphery, the Managing Director of Imperial Airways, who had intended to be present at the meeting, had been detained at the last minute and had found it impossible to attend. Undoubtedly, however, he would like it to be stated that Imperial Airways were very highly appreciative of the work that the Deutsche Lufthansa had been doing towards the solution of the many problems

associated with flying and landing in fog; it was quite evident that they had advanced a long way along the road towards success.

As had been pointed out in the paper, ice formation was one of the really serious problems in connection with bad weather flying which still remained completely unsolved. He had been very much interested to note the statement that the past winter had been a particularly bad one, for that had been the experience of Imperial Airways. The weather had not perhaps been so turbulent as was often the case in Western Europe during the winter, but in other respects it had been an exceptionally bad winter. One of the worst features had been an epidemic of ice formation, whereas ice formation had not been experienced to any great extent in Western Europe for some winters previously. It appeared that there was as yet no known way of overcoming ice formation on wings, so that the only thing one could do was to avoid flying in conditions when ice formation was likely to occur. That, however, was not always an easy matter. The experience of Imperial Airways was that it was usually possible to fly either above or below the level at which ice formed; there was generally a fairly clearly defined level at which the atmospheric conditions were particularly favourable to ice formation. On some occasions, however, it was exceedingly difficult for pilots to avoid flying through these conditions. He asked if the Deutsche Lufthansa had collected any information of a meteorological nature which would enable the ground organisation to forecast the presence of conditions which were likely to cause ice formation.

Again, he asked if the Deutsche Lufthansa had found that any one class of aircraft was more liable to ice formation than another. Imperial Airways had found very definitely that there was a difference in respect of the liability of the different classes of aircraft to suffer from this trouble. The high-lift monoplane type appeared to be much more susceptible to serious ice formation than the biplane; Imperial Airways had experienced no case of serious ice formation on the leading edges of the wings of biplanes, but with high-lift monoplanes the trouble had certainly been experienced, sometimes quite seriously. He was unable to give an exact explanation, but he imagined it was due to the fact that with a high-lift section there was a greater depression just behind the leading edge, so that in the particular atmospheric conditions which gave rise to this trouble there was a greater tendency to start the formation of ice on the leading edge. Once the formation started it tended to grow very rapidly.

Another question he would ask was whether the Deutsche Lufthansa were investigating the possibility of marking wireless masts and other lofty obstructions by any form of signalling apparatus, such as radio or magnetic apparatus, which would communicate to a pilot the fact that he was approaching such an obstruction?

The conditions in which they were flying nowadays, and the conditions in which they hoped to fly when the problem of operation in fog had been completely solved, were such that the mere lighting of obstructions would be useless; and it seemed that it would be necessary to provide some reliable means by which the aircraft would automatically pick up a signal of some kind when approaching a danger zone.

Mr. R. P. G. Denman (A.F.R.Ae.S., Airwork, Limited): He had commenced the preparation of a paper on wireless and civil aviation, which he had proposed to present to the Council, when he had received news of Dr. Stüssel's promised contribution on this very important part of that subject. It was a special pleasure to him, therefore, to be able to congratulate Dr. Stüssel on a really authoritative and admirable paper. Dr. Stüssel had put the requirements for a blind landing system quite simply when he had stated that they had to know the direction of flight, the distance from the airport and the altitude above the ground, *i.e.*, there were required two lengths and one angle. More generally, two co-ordinates or bearings would suffice to fix a point in some horizontal plane,

a third measurement, made in either of these two forms, then giving the height. But inasmuch as the co-ordinate version (height above the ground) could be obtained from an altimeter—and Dr. Stüssel had said that progress in altimeter design was far from being at a standstill—it might be agreed that this problem of determining the third co-ordinate was not fundamentally a wireless problem. If they accepted that, they had then to consider how far it might be desirable at this stage to standardise a wave length for the apparatus necessary to give the other two factors. He believed—though it was not mentioned in the paper—that the predominant factor leading to the choice of a 9-metre wave in the Lorenz apparatus had been the desire to obtain a vertical transmission characteristic which would enable a continuously directed gliding approach to be made in the same manner as was done in the United States. It had been pointed out already that by doing so the problem of hunting about the path of approach was created. That being so, he asked if Dr. Stüssel would agree that, where no obstructions existed around a particular aerodrome, a non-directional form of beacon, with a head-on indicating device in the machine, would suffice.

Finally, Mr. Denman expressed the hope that in choosing the wave length for the beacons due regard would be given to the possibility of using the same wave length for the purpose referred to by Major Mayo, *i.e.*, the marking of obstructions—a problem which must be regarded as second only to that of fog landing in its urgency.

Mr. M. L. Bramson (F.R.Ae.S.): He had understood from the paper that the guidance of an aeroplane through the approach corridor between obstacles was an even greater problem than that of the actual landing. It seemed, as the Chairman had already pointed out, that that problem was almost completely dealt with if the angle of approach were sufficiently steep, as it would be for an autogiro; therefore, the use of the autogiro would reduce by one the number of highly accurate co-ordinates that would be required in order to make a successful blind landing.

Secondly, he asked whether it had occurred to Dr. Stüssel, or to anyone else who was dealing authoritatively with the problem of fog landing, that the angle of glide of a given aeroplane was a definite function of the angle of incidence, and was independent of the loading of the machine. Thus, if the problem of fog landing involved, first, finding a point in space situated at a definite distance from the aerodrome at a given height, then if a gliding angle were standardised—he was talking of fog conditions and, therefore, the probability of there being no wind—the problem would be simplified. A standard angle of incidence, which could be controlled by the pilot by means of an incidence indicator—such indicators existed, and he believed the most successful was a French one invented by M. Constantin—would in no wind give a constant gliding angle and presumably that could be substituted for the means now adopted for guiding a machine along an inclined line from the point originally found before starting the landing operation.

Though he was only faintly familiar with the causes of ice formation, he imagined that the first cause was condensation of moisture on the surfaces and subsequent freezing due to rapid evaporation; he asked if he were right in that. If so, it would appear that some method of repelling the deposit of condensation on the plane, utilising electrostatic forces (which had been employed for repelling other deposits) might be considered.

Mr. R. A. Watson Watt (National Physical Laboratory): With reference to the utilisation of the 9-metre wave length for guiding, one of the crucial difficulties he would have expected in using these ultra-short waves was the very general radio " lighting up " of the surroundings of the sending beacon and of the conducting surroundings of the receiving installation. It had been stated in the paper that one of the great advantages of using these ultra-short waves was the very efficient radiation, and consequently reception, that could be obtained

on small lengths of conducting material. But one felt that that carried with it the compensating disadvantage that there were very many potential re-radiators of comparable wave length near a ground installation and equally on the aircraft, and he would suppose that the fields around the sender, and the field distribution around the receiving dipole, would be so complex and distorted that the occasions on which one could get a clearly marked zero, for example, would be very rare indeed. He would like to know whether his fears in this respect were unfounded.

Mr. F. S. Barton (Royal Aircraft Establishment): The experience at the Royal Aircraft Establishment had been that the use of radio as an aid to fog landing, without a proper consideration of the problems of aircraft stability—he was referring to stability in control of the aircraft—led one into trouble. It was due to the appreciation of these problems that the Royal Aircraft Establishment had been led to put forward the system of merely gliding down from a point in space, fixed originally by a balloon, but in the future, he hoped, by radio, as against other systems in which vertical and horizontal guiding beams were used to carry the aircraft right to the point of landing.

He was very interested to note the whole-hearted co-operation which Dr. Stüssel seemed to have received both from the commercial radio interests and from Government Departments. It seemed that they had all worked very happily together, and had produced at least a practical scheme. No reference was made in the paper, however, to the accuracy of the 9-metre signal beam. The accuracy was adjustable to some extent, with a sacrifice of range, but Mr. Barton asked for information as to the accuracy in degrees, *i.e.*, the actual angular width of the signal path. He also asked what type of indicating instrument would be used, and what were the methods by which the indications were obtained from the radio field pattern and given to the pilot.

The use of a 9-metre wave length meant that the operating companies—at least in the case of the Deutsche Lufthansa—were definitely prepared to carry extra equipment for the purpose of securing assistance in bad weather landing. There was a possibility that, with the use of the radio azimuth, one wave length could be used for communication as well as for the directional indications. It might be, however, that from the radio operating standpoint it was preferable to have the two wave lengths, and it appeared that the extra weight which that involved was considered worth while by the various interests concerned.

Mr. J. R. Cunningham (United Air Lines): The problems confronting air transport, to make possible scheduled flights regardless of weather, as discussed by Dr. Stüssel in his paper "The Problem of Landing Commercial Aircraft in Fog," are in accord with American ideas of the difficulties to be overcome before such flights can be routinely made by commercial aircraft.

The first problem, that of conducting scheduled flight from the point of departure to destination with due safety regardless of weather, is—it is agreed—well beyond the stage of experimentation and it would appear that in the U.S.A. they are working along essentially the same lines as those indicated by Dr. Stüssel.

The second problem is that of instrument landings after arriving over the point of destination. In order to further reliability and safety of such flight and landing, United Air Lines, Inc., has in every possible instance duplicated those instruments necessary to flight entirely by instrument—the directional gyro supplementing the turn indicator clock and the magnetic compass; the artificial horizon supplementing the ball-bank indicator and the rate of climb indicator, all of which instruments have been developed to a sufficiently high degree of reliability that the pilot may depend upon them with as much confidence as he depends upon his motors.

To overcome the possibility of failure of these instruments, United Air Lines, Inc., has done away with both the venturi type drive and the use of suction from the engine, standard practice now being to use two suction pumps (one mounted

on each engine), either one of which is capable of operating all the gyro instruments, although both pumps are in operation all the time—the excess suction being by-passed through a relief valve. This gives reliable functioning of these instruments while on the ground before take-off.

As a measurement of altitude for en route flying, the sensitive barometric altimeter has proved to be quite satisfactory. Correction for changes in barometric pressure are given the pilot in flight by radio from a duplicate instrument, each of our ground stations being provided with an altimeter identical to that carried on the plane. All altimeters in airplanes and at ground stations are checked against a master instrument at frequent regular intervals. In actual tests over a period of time, it has been found that (by use of this method of checking) they are able to hold the aircraft altimeter to within a plus or minus ten-foot error. A static lead taken from the airspeed indicator pitot head (which is electrically heated) avoids changes of pressure in the cockpit affecting the altimeter.

The automatic pilot has unquestionably been developed to an extent which makes it commercially practicable.

In contrast to the wireless telegraphy mentioned by Dr. Stüssel, they have found that the use of radio telephone communication has proved dependable and more readily and quickly usable by the pilot. Direction finding by means of radio bearings from ground stations has not been a subject of study or experiment here to any extent since about 1928, their efforts being expended in the development of a system of radio beacon signals received by the pilot from radio beacon stations. Their theory has been to provide the pilot with all the navigational information needed for instrument flight in the airplane itself, without depending upon advice or instruction from the ground.

They have experienced the same unreliability of the radio range beacon, due to night effect, as that noted by Dr. Stüssel and also the effect of terrain on range beacon signals, but the introduction of the T-L (Transmission Line) type of radio range beacon antenna has gone a long way toward eliminating these effects. Across flat stretches of country, the radio range beacon has proved to be reliable as a homing device. They believed, however, that closer spacing of the range beacons through mountainous terrain will be necessary before the range courses across such terrain will become thoroughly dependable. The present spacing of range stations is approximately 200 miles. This will probably have to be reduced to about 100 miles through mountainous country, in order to obtain satisfactory results.

As stated by Dr. Stüssel, a means to prevent excessive formation of ice on the airplane is essential during the winter months. The development of such means has been slow. Two years ago, the B. F. Goodrich Rubber Company brought out a type of de-icer consisting of a rubber overshoe which was applied to the leading edges of the airplane wings and tail surfaces. This shoe was inflated by means of an engine-driven air pump designed for the purpose and using a distributor valve driven by a tachometer shaft from the engine, inflating in rotation the shoe on each wing and tail surfaces. Each shoe automatically deflates itself, due to the tension of the rubber. This type of de-icer, in practical flight tests conducted over a two-year period proved only fairly satisfactory.

United Air Lines, Inc., has recently improved the reliability of this type of de-icer by using the exhaust of the two pumps used for gyro instrument operation to provide the pressure needed to inflate shoes consisting of a number of fabric tubes laid lengthwise of the leading edges of the wing and tail surfaces, each group of tubes being covered with a sheet of rubber attached to the skin of the wing and tail surfaces. Either pump will supply sufficient pressure to inflate these shoes. The distributor valve, driven by a small electric motor, has nine ports and inflates two tubes at a time successively, requiring forty seconds to make a complete cycle. In service tests, this type of de-icer has successfully

demonstrated that it will keep an airplane free of ice to such an extent that flight can be maintained for protracted periods under ice-forming conditions.

The propellers of the airplane are protected from ice formation by the use of a rubber-covered spinner and a rubber covering applied to each propeller blade for about one-third of its length from the propeller hub. This rubber is coated with a special type of oil.

The problem of making instrument landings routinely possible by commercial air transport is undoubtedly still in the experimental stage, but they agreed with Dr. Stüssel that rapid strides are being made toward overcoming this last problem confronting commercial air transport. The " ZZ " system described by Dr. Stüssel is somewhat comparable to the present Army system of instrument landing, except that in the case of the Army system all means of determining proper approach lane are determined directly by the pilot by means of a radio compass; distance from field is indicated to him by small radio markers placed at given distances from the field, all ground radio equipment being mobile and properly set out by the ground crew just previous to plane landing.

A serious difficulty presents itself in using this system, since the pilot must depend entirely on his sensitive altimeter for all indications of elevation above the ground or nearby obstructions. However, many successful landings have been accomplished on test flights entirely by instrument by pilots in a hooded cockpit plane.

The system for landing entirely by instruments, which to date has proved most accurate and appears to give the most promise for commercial use, is that developed by the Bureau of Standards employing:—

1. A runway localiser which is in reality a miniature radio range beacon operating on about 300 kcs., laying its course directly down the centre of the runway to be used.

2. A landing beam indicating the correct gliding path for the landing plane by use of constant reception field strength on a frequency of about 100,000 kcs. This gliding path is adjustable and can be trained above all obstructions.

These two units give indication of the proper gliding path visually on a single indicator, the runway localiser indications being shown by a vertical needle, the landing beam giving its indication by a horizontal needle. Supplementing these two units are two small radio markers placed along the gliding path of the airplane—the first marker approximately 2,000 feet from the edge of the field, the second at the edge of the field. Signals from these markers are picked up aurally by the pilot and are distinguishable by the different characteristic note put out by each.

The system, as outlined above, has given very good results in test flights conducted by quite a number of our pilots, many of them having become quite proficient in its use. An improvement to the above system, which will make it adaptable to commercial use and which is now in process of construction, is the installation of both the runway localiser and the landing beam transmitter and antenna underground at the centre of the airport, both units capable of being rotated through 360°. This will make it possible for a pilot to approach the field and land by instruments from any direction—a very necessary feature to compensate for differences in wind direction and velocities. Test flights on this type of installation have been made and the results are very encouraging.

They concurred with Dr. Stüssel that the problem of instrument landings is now a very important question, requiring urgent consideration, and they believed that, by making slight changes and refinements in the above outlined system, they were approaching the time when instrument landings can be made a routine part of commercial operation.

Reply to Discussion

(1) In reply to the question put by the Chairman regarding the meaning of the term " bad weather conditions," it may be said that in my lecture this is intended to mean all weather conditions which give rise to difficulties in carrying out flight or landing. The term includes conditions in which the landing at the terminal airport is rendered difficult by low clouds or by mist reaching to the ground.

The provisional " ZZ " landing process described has provided very valuable assistance during bad weather conditions in which low clouds are present, but was not sufficient for landings with bad weather conditions when fog was encountered at the terminal airport. The new investigations and work described should, by progressive development, lead to a process which can also be utilised with bad weather conditions in which thick fog is encountered at the terminal airport.

(2) The Chairman requested the representatives of air transport companies present to say whether serious difficulties did not arise in the case of fog landings carried out only with the assistance of the readings from one or more instruments. With regard to this question, I should like to associate myself with the remark made by Captain Walters. Before giving a final reply to this question one should wait for the further detailed results of the investigations, and at the same time consider carefully the character of error possible. It is my opinion that a certain expression to rely on the readings from instruments for such a procedure in flights carried out with the assistance of instruments only is not justified by experience.

(3) The statements made by R. S. Capon regarding the direction in which English investigations are proceeding were of particular interest to me. The most important difference from the German method is that the aeroplane is conducted through the zone of obstructions directly to the airport not by means of readings from instruments but—for simplifying the instrument equipment—one limits oneself to conducting the aeroplane to a favourable point in the vicinity of the port whence it is possible for the aeroplane to glide to the landing place with the assistance of the compass, while keeping to a definite gliding angle. For my part, I am convinced that such a process permits the use of a simpler set of instruments, but fear that experience of bad weather landings has shown that the use of the method in air transport would entail considerable difficulties in consequence of the obstructions which generally surround airports.

(4) Immediately connected with this discussion is also the question mooted by Messrs. Capon, Denman and Barton, namely, whether for guiding the aeroplane to the port a radio compass provided on board which would indicate direction to a transmitter located at the port is more advantageous, or whether the indication of the path of flight through the obstructions by means of the guiding ray process, as practised in Germany, is preferable.

In deciding this question the nature of the obstructions surrounding the airport is likewise an important consideration. The continuous indication of direction by a radio compass should in all cases be a sufficient assistance for approaching an airport when there are no obstructions which render this difficult. When, however, as in most cases in air transport, it is necessary to approach the airport through a limited zone of obstructions, such indication of direction by means of a radio compass may be insufficient, particularly when the direction of the wind changes with the altitude. I therefore think that in air transport it is necessary to fix the path of flight through the zone of obstructions by means of a guiding ray system.

In this connection Mr. Capon directs attention to the fact that difficulties were experienced in keeping to the course when flying with the assistance of the guiding ray system, and in the absence of a fixed direction the path of flight was covered in " S " movements. It is clear that when flights are conducted with

the assistance of the guiding ray system such a path of flight may occur, because the wireless signal of the beacon gives orientation but no information as to direction. It is possible to avoid such variations, of course, if use is made of a direction sensitive apparatus (compass or turn indicator) provided on board. According to the experience of the Deutsche Lufthansa, flying with the assistance of the guiding ray is facilitated when the direction of flight is not in the middle of the zero zone, but at one of the edges. In any case, none of the difficulties referred to has been encountered in the operation of the Deutsche Lufthansa. Perhaps the kind of guiding ray, particularly the magnitude of the zero zone—about which Mr. Barton also enquired, plays a part in this question. According to the results of experiments, the opening angle of the zero zone is preferably $\pm 3°$. I think, however, that the difficulties which occur in this connection have to be overcome, but they are by no means insuperable.

In this connection Mr. Barton mentioned that he would like to have some detailed information regarding indicating instruments, and I would suggest that it would be well for him to get into touch personally with the appropriate German concerns.

(5) The guiding ray process employed in Germany operates with a wave length of 9 m. Several questions were asked regarding this.

The Chairman directed attention to the possibility, with 9 m. wave length, of interference with reception by the magnetos of power-driven aircraft. Experiments have shown that in order to avoid disturbing radiation it is advisable to screen off the ignition device of aircraft in the manner generally employed nowadays. According to available experience, however, no measures are necessary beyond this. In particular, no disturbing influences on the reception caused by magnetos of power-driven aircraft or other vehicles have been observed, nor need they be feared.

Mr. Watson Watt referred to the possibility of the radiation diagram of the 9 m. beacon being much disturbed by the reflections from the neighbourhood of the transmitter, and also by similar effects from the vicinity of the receivers. Such reflections do occur, but disturbance of the direction reception can easily be avoided. As the action of reflection with the 9 m. wave length is possible only at relatively short distance, the *transmitter* experiences no difficulty in avoiding disturbing reflection if the place of erection of the antennæ unit is carefully chosen. In the case of the *receiving apparatus* it is in any case advisable to choose a favourable place of erection in the aeroplane by means of a receiving characteristic. As, however, in this investigation, according to the receiving characteristic, it is merely a question of avoiding the destruction of a clear zero in the longitudinal direction of the aeroplane, no serious difficulties need be expected nor have any occurred during all the investigations carried out by the Deutsche Lufthansa.

Mr. Mayo enquires whether the Deutsche Lufthansa has already conducted investigations regarding the indication of obstructions with wireless apparatus. Mr. Denman refers to the same point and states that the 9 m. wave length can also be used for this purpose. I must remark that the Deutsche Lufthansa has not yet dealt with this question. But from the knowledge of the properties of the 9 m. wave length and the experience hitherto gained, such an application is quite possible. The best indication is perhaps the use of apparatus with 9 m. wave length for the preliminary signal mentioned in the lecture, as in this case the requirements are similar to those in the indication of obstructions.

I would again lay stress on the remark made by Mr. Barton that the possession of a separate receiver necessitated by the use of the 9 m. wave length, in view of the advantage in operation afforded by this double wireless connection, appeared to be advantageous. As in the case of any additional apparatus, this special receiver is an unpleasant addition to the existing extensive equipment, but on the other hand it appears to be of serious importance that precisely during

this difficult landing manœuvre a satisfactory information service is ensured which operates independently of the auxiliary devices for landing.

(6) Mr. Bramson points out that the problem of landing in bad weather is very much simpler with an autogiro aeroplane owing to the considerably steeper gliding angle possible therewith. I fully agree with this opinion. Unfortunately, however, there is hardly any hope of the problem of landing in bad weather in air transport being solved by this means in the near future.

Mr. Bramson also referred to the use of an angle of incidence meter for guiding the aeroplane into the port with constant gliding angle. I do not think that such a use of the angle of incidence meter is advisable. On the one hand, Mr. Bramson's assumption that the relation angle of incidence to gliding angle is independent of the load is not correct. On the other hand, the possibility of dead calm assumed by Mr. Bramson is not always present. In a large number of cases in which the technical auxiliary devices must be utilised for landing in bad weather, the obstructions are closely surrounded by clouds and strong winds prevail.

(7) Several references were made to the question of the formation of ice on aeroplanes in bad weather landings. Mr. Mayo asks to what extent, according to the experience of the Deutsche Lufthansa the meteorological information regarding the danger of formation of ice is reliable. In reply, it must be said that an advice regarding the occurrence of zones involving the danger of formation of ice is extraordinarily difficult, because the regions of danger are often local. It is the general impression, however, that the knowledge possessed by meteorologists on this subject is becoming more extensive and the information has become more reliable.

Mr. Mayo also refers to the observation of the Imperial Airways regarding the varying behaviour of monoplanes and biplanes when ice is formed thereon. As biplanes are not used in the Deutsche Lufthansa service, no experience is available on this point. In spite of the fact that the cross-section of the wings of the type of aeroplane in the Deutsche Lufthansa service varies very considerably, no clear information has been obtained regarding the varying behaviour of these types of aircraft when ice is formed thereon. But perhaps the observations made are not sufficient to enable one to arrive at a clear conclusion regarding the dependency of the ice formation on the type of wing construction.

Mr. Bramson has also a few words to say regarding the formation of ice on aeroplanes. The assumption that the cause of the formation of ice is an accumulation of moisture which freezes in consequence of rapid evaporation is, in my opinion, incorrect. On the contrary, the coating of ice is due to the aeroplane meeting strongly sub-cooled water in the form of droplets or vapour, and the freezing which then occurs.

(8) I noted with particular interest the remarks of Mr. J. R. Cunningham, of the United Air Lines, Chicago, regarding my lecture, which were subsequently sent to the Royal Aeronautical Society. The opinions, experience and plans of the American air transport company are a very valuable addition to the problem of flight and landing in bad weather, which is here considered from the point of view of European experience.

THE SILENT FLIGHT OF OWLS

BY

LIEUT.-CMDR. R. R. GRAHAM, R.N.

It is possible to trace, in the flying equipment of birds, feathered versions of many of the refinements that render the modern aeroplane more efficient than its predecessors. It would, therefore, be a mistake to ignore birds as a guide to possible future developments. One of the most interesting groups of birds is that which includes all the owls, for there is a possible connection between the manner in which their strikingly silent flight is achieved and the increasingly pressing problem of silencing airscrews.

Peculiarities of Owls' Feathers

In the detailed design of their surface texture, the wings of owls differ greatly from those of all other groups of British birds.* Their peculiarities can be placed under three headings:—

(*a*) *The Leading Edge Comb.*—There is a remarkably stiff, comb-like fringe on the front margin of every feather that functions as a leading edge. The teeth of this comb are extensions of the barbs, or fibres, that form the front web of the feather. They vary in length and in distance apart according to the size of the bird and to their position in the wing. The largest of them are 4.0 mm. in length, and 0.75 mm. apart.

(*b*) *The Trailing Edge Fringe.*—Along the trailing edge of the main wing and of each primary feather, there is a fringe somewhat resembling the fringe of a shawl or towel. Its breadth, in large owls, is 5.0 mm. The fibres of which it is formed are extensions of the barbs that make up the rear web of the feather. They are exceedingly flexible, and lack the microscopic hooks that cause the main parts of the barbs to cling together and form the web.

(*c*) *The Downy Upper Surface.*—Certain parts of the upper surface of the feathers are covered with a fine, short down.

An Unsilenced Owl

Before going on to describe how the three special modifications of owls' wings may possibly effect silence, mention must be made of a bird that is tantamount to a living proof that these are indeed silencing devices. This is the fishing owl of tropical Asia, which goes by the Latin name of Ketupa Flovipes. There is no doubt at all that the bird is a true owl, but it differs from the rest of its race not only in being a fisherman, but also in having normal unmodified feathers. It can only be supposed that, in the process of evolution from the parent stock, this owl has either shed the modifications or has never developed them, for the reason that its special prey, being submerged, is unable to hear

* There is one exception—the Nightjar, which, like the owls, flies by night, or at dusk. The development of the special modifications to its wings is less than in owls, but, for the purpose of this paper, the bird may be included among them.

the noise of its wings. Not requiring their aid, the bird is the better for being without the devices, for they must, by adding to the drag of a wing, reduce its efficiency as such.

The Hunting Methods of Owls

What, then, are the tactics of the normal owl that they should call for silence in flight? Consider a typical and familiar member of the tribe—the Barn Owl. Its prey consists of mice, voles and other small creatures, whose hearing, there is every reason to believe, is most acute. The bird's habit is to cruise slowly along over the fields, at a low altitude and in such a way that, in daylight, its intended victims would see it approaching and would have

FIG. 1.

The first primary of Bubo Bengalensis—an owl of normal habits, but closely resembling Ketupa Flovipes.

FIG. 2.

The first primary of Ketupa Flovipes—the fishing owl.

time to escape. But, hunting as it does in the dark or at dusk, the Barn Owl can approach, unseen, close enough to pounce and make its capture. In this it is aided by the abnormal size of its eyes. For these tactics, silenced wings must be a great help, even though they entail sacrifice of speed. It is noteworthy that the Little Owl, which is the most diurnal of the British species, lacks the comb on the leading edge of its wings.

Compare these tactics with those employed by birds that hunt ground game by day. The kestrel and the golden eagle are good examples. A bird of this type, having spotted its prey from a considerable height, turns head on to the objective and dives at terrific speed. Being head-on, and having its wings folded back, the bird presents its smallest aspect, and is unlikely to be seen by the victim. The speed of approach is so great that the rushing sound produced in the dive does not give warning in time for escape, while the noises of flight, made previous to the dive, are deadened by distance. It would not matter much if these latter sounds were audible, for in the daytime, as compared with the night, the air is full of birds; and it is unlikely that a mouse, hare, or vole would take shelter at the noise of every passing wing. If it did, it would lead

a hopeless life of constant alarm. Noisy flight, then, for birds that prey by day is no handicap, while high speed is essential.

The Leading Edge Comb

For the purpose in hand, it is desirable to ascertain whether the special modifications of owls' feathers are designed to subdue sounds produced by friction between the feathers, or those due to fluctuations in air flow. Take first the leading edge comb. In the Barn Owl this extends from near the tip to the root of the foremost feather in the wing and for a short distance along the alula.

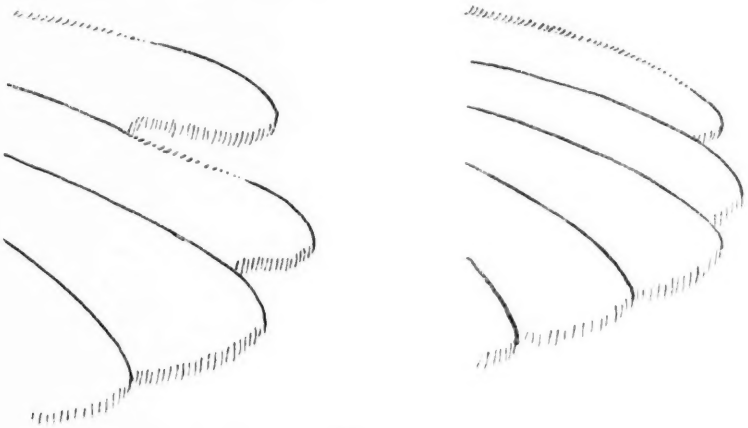


FIG. 3.

Left—The wing tip of the short-eared owl. The comb on the first feather ceases at the point where the feather, being emarginated, is free to bend and twist. That on the second feather is present where, owing to being emarginated, it acts as a leading edge.

Right—The wing tip of a barn owl. In this there is no comb on the second feather as, being un-emarginated, it does not act as a leading edge.

It is present, then, only on the true leading edge which is never overlapped and which, in flight, makes contact with the air alone. In this species, it seems safe to say that the comb is designed to deal only with fluctuations in the air flow.

But what of other owls? The Short-Eared Owl has an additional short length of comb on the second primary feather, while certain species, including a close relative of the fishing owl, have a comb on no less than four feathers. But in all these birds the extra lengths of comb are present only on such parts of the feathers as are emarginated (cut away in breadth) in order to form the wing-tip—or thrust—slots, which were described in this Journal, of January, 1932. Being emarginated, these parts of the feathers separate from their anterior neighbours during the down stroke of flapping flight and, therefore, constitute secondary leading edges. Since they cut the air as surely as does the main leading edge of the wing, they require, equally, to be silenced.

With this evidence to hand, the question of the effect of the comb on the air flow, and hence upon the suppression of noise, can be considered.

The noise produced by an aerofoil is said to come from the region in rear of the leading edge of the suction surface where there is a sudden fall in air pressure. This noise is, perhaps, augmented by sounds emanating from the region in rear of the trailing edge where the lower air stream at high pressure

mixes with the upper stream, which is not only rarified, but is travelling at higher speed. There may also be sounds produced through oscillations of the trailing edge.

The comb, in a Barn Owl's wing, is so placed that the air stream which is destined to become the boundary layer flowing over the wing must pass up through it before reaching the true leading edge. The most obvious effect will be a reduction in the speed of this air by the time it reaches the leading edge. It is conceivable that this has a silencing effect by reducing the suddenness of the fall in pressure in the boundary layer.

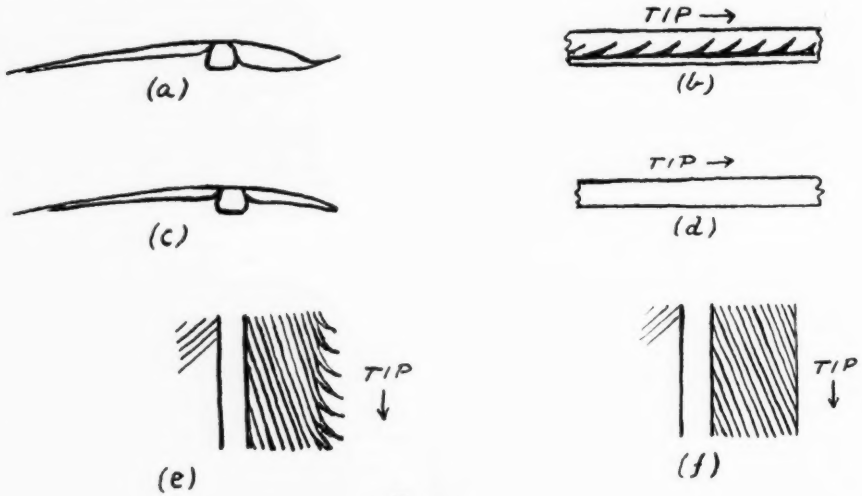


FIG. 4.

Sections of feathers enlarged to show detail.
(a) Cross section of a typical silenced feather.
(b) Leading edge of a silenced feather viewed from in front.
(c) Cross section of a typical unsilenced feather.
(d) Leading edge of an unsilenced feather viewed from in front.
(e) Part of the leading edge of a silenced feather seen from above.
(f) Part of the leading edge of an unsilenced feather seen from above.

There are two additional effects. Careful scrutiny with a magnifying glass discloses the fact that each tooth of the comb juts out with a slight upward inclination from the leading edge, and is also inclined towards the tip of the wing at an angle of about 45 degrees; further, that each tooth is really a blade, set at much the same angle of incidence as the slat of a Handley Page slot, in the open position. This means that the boundary layer, on arrival at the true leading edge, will have been given momentary wash-out, and will have been deflected so as to flow more closely over the upper surface of the wing than it does in normal feathers.

The wash-out may well have a silencing effect, for an airstream striking the leading edge of a wing at any angle other than the normal should produce proportionately less noise.

The down-wash resulting from the slot effect possibly reduces noise by raising the pressure immediately in rear of the leading edge.

Support is given to these theories by the variation in development of the comb in different parts of the span of the wing. The teeth are longest in the middle of the wing, diminish outwards and inwards along the span, and are

entirely absent at the tip and root of the wing. In mid-wing, the teeth have bristle-like extensions, normal to the leading edge, which must greatly increase the braking effect on the air flow. The comb, then, is apparently designed to have the greatest effect in those parts of the wing where the incidence in the down- or power-stroke of flapping flight is thought to be greatest. There can be little doubt that the greater the incidence, the more tendency is there for

FIG. 5.

Detail of a silenced owl's first primary feather. This photograph was taken from below looking towards the feather-tip. The teeth of the comb appear very fine because from this angle they are seen edge-on.

FIG. 6.

For comparison with Fig. 5. *This was taken from below looking inwards from the feather-tip. The teeth appear thicker because the minute blades are normal to the line of vision.*

sound to be produced. The reason for the presumed variation in incidence itself is that the root of the wing has but little downward movement, while the tip is sufficiently flexible to give to the pressure of the air and be twisted rear edge up in the air stream that it encounters.*

The theory that wash-out has a silencing effect is given additional support by the absence of comb at the wing tip, for here the air is already washed-out,

* The fact that the alula or bastard wing, which is nothing less than a slot, is situated in mid-wing, supports the view that the incidence is greatest there.

owing to the feathers being bent upwards as well as outwards by the reaction of the air they displace. This distortion of the wing tip is shown clearly in many photographs.

The Trailing Edge Fringe

Because the trailing edge fringe is present on the rear margins of all the primary feathers, it well might be thought that its purpose has to do with reducing friction between overlapping feathers. On the other hand, its presence along the trailing edge of the whole of the main wing and on the rear margins of the separating emarginated feathers indicates the reverse. Further consideration, in fact, tends to show that the fringe is designed to deal with air flow alone. To start with, think of the effect it must have on the air flowing off the wing at the trailing edge. At the junction of the upper and lower streams it is not improbable that small vortices tend to form from which sounds emanate, but in the owl's wing the lower stream, before breaking into the upper, will have had, for a short space, to pass through the fringe. It is suggested that the process of mixing is thereby delayed and that the combined stream is smoothed, or combed out, in such a way that the noise-producing vortices do not form. That is all very well, as far as the trailing edge of the main wing or of a separating feather is concerned, but some other explanation is required to account for the presence of the fringe on overlapping feathers. Here, the up- or return-stroke must be brought into the picture. In the up-stroke of normal straightforward flapping flight the feathers remain closely packed together, the whole wing blade twisting into the attitude of least resistance, but when a bird is hovering or semi-hovering, as owls frequently do, the feathers, owing to the manner in which they overlap, separate and allow the air to flow through from the top to the bottom of the wing. This also is shown distinctly in photographs. It occurs because the wing itself is unable to twist sufficiently. Now when the air is flowing through the wing in this way, it possibly causes the trailing edges of the feathers to flutter and produce sound. If this is so, the fringe must act as a damper and effect silence. It is possible that the sole purpose of the fringe on any part of the wing is to prevent fluttering of the trailing edges.

The Downy Upper Surface

In the feathers of all day-flying birds the upper surfaces of the broad rear webs of the primary feathers are covered with an enormous number of microscopic hooks. Their duty, in the down-stroke, is to interlock with the fibres of the leading edge of the overlapping feather next in rear, and so render the wing a compact whole. Since they all face the same way, the hooks loose their hold in the up- or return-stroke and allow the wing partially to fold. By trial with feathers held in the hand it can be shown that the process of unlocking and relocking these hooks creates an audible rustling noise. In the owls the barbicels, or upward-protruding fibres from which the hooks branch out, are very greatly lengthened so as to form a loose, downy surface. It can be seen, then, that this peculiarity of owls serves the purpose of damping down the noises which would otherwise be produced by the feathers sliding over each other and locking. It is, therefore, of no particular interest where the silencing of airscrews is concerned.

The anterior web of an owl's feather also has a downy covering, but this is of a more compact character resembling velvet and there are no hooks on the fibres of which it is formed. This shows that it has nothing to do with interlocking, while its position indicates that it is not connected with overlapping. The front edge of a feather is only overlapped when the wing is folded. It can only be presumed that the purpose of the down in this area is in some way connected with air flow; possibly with the sharp drop in pressure in rear of the

leading edge. It may serve the purpose either of muffling the minute reverberations of sound emanating from that region, or of continuing the retardation of the boundary layer initiated by the leading edge comb. Like the leading edge comb, the down is absent at the wing tip, where the incidence is low and where the air stream is washed out.

Conclusion

There are two characteristics of the flight of owls that militate against the possibility that their silencing modifications might be adapted to airscrews. Firstly there is the wing loading, which is lighter than in any other group. It is, however, only a little lighter than in eagles and the like, and these are notoriously noisy in flight. It would seem, then, that although the light loading of an owl may assist silencing by permitting a slow flap and small angles of incidence, its main purpose is to permit the bird, without difficulty, to carry the extra weight of its victims. Secondly, there is the low speed of the wings, which is in no way comparable with that of airscrew blades. Unfortunately there are no birds with high-speed wings, such as the partridge, that require silent flight, but it is not impossible that without creating excessive drag, modifications of sorts would be as effective at high speeds as at low. They would, at least, have more decibels on which to make a start.

ABSTRACTS AND NOTICES
FROM THE
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(Prepared by R.T.P.)

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LIST OF ABBREVIATIONS OF TITLES OF JOURNALS.

Aeron. Eng.	Aeronautical Engineering.
Airc. Eng.	Aircraft Engineering.
Ann. d. Phys.	Annalen der Physik.
Army Ord.	Army Ordinance.
Autom. Absts.	Automotive Abstracts.
Autom. Tech. Zeit.	Automobiltechnische Zeitschrift.
Autom. Eng.	Automobile Engineer.
Autom. Ind.	Automotive Industries.
Bell Tele.	Bell Telephone Laboratory.
Bur. Stan. J. Res.	Bureau of Standards (U.S.A.) Journal of Research.
Chem. Absts.	Chemical Abstracts.
Chem. and Ind.	Chemistry and Industry.
F.G.I.	Forschung auf dem Gebiete des Ingenieurwesens.
Fuel.	Fuel in Science and Practice.
H.F. Technik.	Hochfrequenztechnik und Electroakustik.
Ind. and Eng. Chem.	Industrial and Engineering Chemistry.
J. Aer. Sci.	Journal of the Aeronautical Sciences.
J.R. Aer. Soc.	Journal of Royal Aeronautical Society.
J. Frank. Inst.	Journal of Franklin Institute.
J. Sci. Inst.	Journal of Scientific Instruments.
L'Aéron.	L'Aéronautique.
L.F.F.	Luftfahrtforschung.
N.A.C.A.	National Advisory Committee for Aeronautics (U.S.A.)
Phil. Mag.	Philosophical Magazine.
Phys. Zeit.	Physikalische Zeitschrift.
Proc. Inst. Rad. Eng.	Proceedings of the Institute of Radio Engineers.
Proc. Roy. Soc.	Proceedings of Royal Society.
Pub. Sc. et Tech.	Publications Scientifiques et Techniques du Ministère de l'Air.
Rev. F. Aer.	Revue des Forces Aériennes.
Riv. Aeron.	Rivista Aeronautica.
S.A.E. Jrnl.	Society of Automotive Engineers Journal.
Sci. Am.	Scientific American.
Tech. Aéron.	La Technique Aéronautique.
W.R.H.	Werft-Reederei-Hafen.
Z.A.M.M.	Zeitschrift für Angewandte Mathematik und Mechanik
Z.F.M.	Zeitschrift für Flugtechnik und Motorluftschiffahrt.
Z. Instrum.	Zeitschrift für Instrumentenkunde.
Z. Metallk.	Zeitschrift für Metallkunde.
Z.V.D.I.	Zeitschrift für Vereines Deutscher Ingenieure.

Aircraft Design, etc.

The Heinkel High Speed Mail-Plane (He-70). (E. Heinkel, Z.F.M., Vol. 24, No. 24, 28/12/33, pp. 669-676.) (5.10/28001 Germany.)

Specification performance of some U.S.A. mail planes are given with engines of 300-500 h.p., speeds of 260-358 km./hrs. (160-230 m.p.h.) and flying weights from 1.74-2.36 tons. German postal aeroplanes in 1932 reached 280 km./hrs. (175 m.p.h.).

The 1932 He.70 shows a test speed of 377 km./hrs. (238 m.p.h. at 660 h.p.) with a flying weight of 3.35 tons. Three general arrangement sketches show the dimensions, and four photographs show the complete aeroplane and some details of construction. Test curves and tables show comparative performance. One international and five German records are claimed.

Interference between Struts. (D. Briermann and W. H. Herrnstein, Jr., N.A.C.A. Report No. 468, 1933, 12 pages.) (5.11/28002 U.S.A.)

Various arrangements of struts of streamline and circular section were set up and the resistances measured independently. The results are plotted graphically in comparison with a single strut.

The effects of varying Reynolds number were examined and recorded. Various types of fairing between strut and span were investigated and interference effects compared. Struts side by side with a spacing of five diameters have little mutual effect. Streamline struts in tandem less than 10 diameters apart may be faired together with advantage.

Six references.

Development in Aeronautics in U.S.A. (K. Schnauffer, Z.V.D.I., Vol. 77, No. 46, 18/11/33, pp. 1239-1240.) (5.14/28003 Germany.)

A series of papers read at the Chicago Meeting of the S.A.E. is reviewed. Reference is made to metal propellers of welded Cr-Va steel. A special magneto-electric testing plant detects manufacturing faults. The formation of ice on struts and wires is said to be an inherent danger in biplanes, and preference is given to monoplanes for flights with low atmospheric temperatures.

Two references.

New British Load Factors. (H. B. Howard, Airc. Eng., Vol. 6, No. 60, Feb., 1934, pp. 37-39.) (5.18/28004 Great Britain.)

A brief account is given of the development of stressing rules during the war and their modification to meet the conditions of civil aviation.

An analysis is given of some of the numerous difficulties in adapting rules to different materials and structures, and the reasons for the changes are stated. The effects of gusts receive particular consideration and are exhibited in a diagram corresponding to a simple formula.

The commentary indicates the need of reasonable flexibility of mind towards any body of rules.

Influence of Rounded Leading Edge on Wing Resistance. (E. Wolff, Ing. Arch., Vol. 4, No. 6, Dec., 1933, pp. 521-544.) (5.20/28005 Germany.)

The conformal representation of a lenticular wing section in a circle is given briefly. An elegant representation on the x-axis of a figure enclosed by three circular arcs is obtained in terms of the hypergeometric series and is applied numerically to a wing section bounded by two shallow circular arcs meeting in the tail at a small angle and rounded off at the nose with a small radius. Calculated pressure distribution results are compared with experimental results and show close agreement except for the calculated peaks at nose and tail which are not observed experimentally.

The so-called profile resistance is discussed in the light of the partial theory available and the total resistance thus calculated is compared with measured resistance. It appears that the rounding of the nose and of the finite angle between the surfaces at the tail reduce the wing resistance appreciably.

Twelve references.

Effect on Lift, Drag and Spinning Characteristics of Sharp Leading Edges on Aeroplane Wings. (F. E. Weick and N. F. Scudder, N.A.C.A. Tech. Note No. 447, 1933.) (5.20/28006 U.S.A.)

From authors' abstract.—In the wind-tunnel investigation free autorotation tests, forced rotation tests, and lift and drag tests were made on modified Clark Y airfoils in the 7 × 10 ft. wind tunnel, and check tests on the lift and drag characteristics at several values of the Reynolds number were made in the variable density wind tunnel. Two different forms of sharp leading edge were tried. Both reduced the maximum unstable rolling moment tending to start autorotation, but neither had a substantial effect on the final rate of free autorotation.

In the spin tests in flight, which were made on a small training biplane, the addition of sharp leading edges produced favourable effects, causing a decrease in the angle of attack and rate of rotation and making the controls more effective. The flight and wind-tunnel tests agreed in showing that the use of the sharp leading edges is accompanied by a substantial reduction in the maximum lift coefficient.

Eight references.

Effect of Rivet Heads on the Characteristics of a 6 × 36ft. Clark Y Metal Aerofoil. (C. H. Dearborn, N.A.C.A. Tech. Note No. 461, 1933.) (5.20/28007 U.S.A.)

From author's abstract.—An investigation in the N.A.C.A. full-scale wind tunnel of a metal-covered 6 × 36ft. Clark Y aerofoil showed about 20 per cent. increase in the profile drag.

Two references.

Charts for Determining the Pitching Moment of Tapered Wings with Sweepback and Twist. (R. F. Anderson, N.A.C.A. Tech. Note No. 483, 1933.) (5.20/28008 U.S.A.)

From author's abstract.—A convenient method for calculating the pitching moment characteristics of tapered wings with sweepback and twist is based on the fact that the pitching moment characteristics of a wing may be specified by giving the value of the pitching moment at zero lift and the location of the axis about which the moment is constant. Data for calculating these characteristics are presented by curves which apply to wings having a linear distribution of twist along the span for a large range of aspect ratios. The curves are given for wings having straight taper and distorted elliptical plan forms. The characteristics of wings of other shapes may be determined by interpolation.

Four references.

Stiffness of Aeroplane Wings. (H. R. Cox, J.R.Aer.Soc., Vol. 38, No. 278, Feb., 1934, pp. 73-107.) (5.24/28009 Great Britain.)

The problem is discussed in reference to forced oscillations in flight, popularly known as wing flutter.

The aeroplane as a whole is a complicated and imperfectly elastic structure, and no general solution is in sight which will allow of comparison of different types. The problem is therefore simplified by assuming certain dynamical similarities in types classified for comparison. In particular, biplanes are separated from monoplanes, and types with wings of unusual dimensions or con-

struction are excluded. Even so, the results would require careful interpretation in the hands of experienced designers.

The flexure and bending of two-spar wings with built-in spars are analysed and the stiffening effects of ribs are considered, the results being illustrated by representative curves of flexure and of bending moments. When the ailerons are put in operation, a torsional moment is imposed on the wings and the wings are warped in a sense which reduces the effective rolling moment on the aeroplane. At a particular flying speed the rolling moment may even become negative. If such a critical speed, denoted as the reversal speed, exists it is found by successive approximations.

An elementary theory is given on the assumption of linear relations between incidence, torsion and rolling moments. Numerical examples are given graphically and methods of computation are given. A technical discussion followed, in which the " reversal " condition was the matter of chief interest.

Sixteen references.

Effect of Aileron Displacement on Wing Characteristics. (R. H. Heald, N.A.C.A. Tech. Note No. 448, 1933.) (5.30/28010 U.S.A.)

From author's abstract.—The aerofoils, rectangular in plan, with 10-inch chord and 60-inch span, were mounted on a model fuselage. Two pairs of ailerons, both with 20-inch span, but with 2-inch and 3-inch chord respectively, were set at angles of pitch of 0°, 12°, 20° and 40°. One aileron and two aileron measurements were found to be in satisfactory agreement. Test data are given in tables and graphs.

Seven references.

Aerodynamic Characteristics of Aerofoils as Affected by Surface Roughness. (R. W. Hooker, N.A.C.A. Tech. Note No. 457, 1933.) (5.30/28011 U.S.A.)

From author's abstract.—The surface was varied from rough to very smooth finish. The effect of a rough area in the region of the leading edge was investigated. Aerofoils with surfaces simulating lap joints were tested.

Measurable adverse effects were caused by small irregularities in aerofoil surfaces. The flow is sensitive to irregularities of the order of 0.0002 cm. near the leading edge. Surfaces simulating lap joints show small adverse effects.

Data from earlier tests of a symmetrical aerofoil show the variation of maximum lift coefficient with the Reynolds number for a polished surface and a very rough one.

Five references.

Tail Buffeting. (W. J. Duncan, J.R.Aer.Soc., Vol. 38, No. 278, Feb., 1934, pp. 108-137.) (5.32/28012 Great Britain.)

Tail buffeting is defined as the periodic change of pressure on the tail unit due to eddies thrown off the wing and superimposing stresses of appreciable magnitude in comparison with usual flying stresses. A careful summary is given of relevant experimental work on the magnitude and distribution of such eddies.

A special apparatus was designed in which an aerofoil comparable with a tailplane was mounted behind a model wing. The tailplane had a spring hinge of adjustable strength and an optical device for recording oscillation. The range of oscillation is shown for different dispositions and it is demonstrated that serious stresses may be superimposed under unfavourable conditions, particularly in low wing monoplane designs. The problem is therefore worthy of consideration by designers. It appears to remain in controversy whether this effect has actually been the cause of accidents.

A discussion follows. Sixteen references.

Reduction in Drag of a Forward-Sloping Wind Shield. (E. N. Jacobs, N.A.C.A. Tech. Note No. 481, 1933.) (5.40/28013 U.S.A.)

From author's abstract.—The drag of the wind shield in the original and a final modified form was determined in the variable density wind tunnel. The final form was arrived at by observations of flow in the smoke tunnel. The flow observations and drag measurements show that most of the large drag added by the original wind shield is eliminated by the modification to the final form.

Drag of Streamline Wires. (E. N. Jacobs, N.A.C.A. Tech. Note No. 480, 1933.) (5.42/28014 U.S.A.)

From author's abstract.—Preliminary results are given of drag tests of streamline full size wires over a wide range of speeds in the N.A.C.A. high speed tunnel. They are directly applicable to full-scale problems and include any compressibility effects at higher speeds.

Protuberances may be employed on conventional streamline wires to reduce the drag. Comparison can be made between conventional sections and strut or symmetrical aerofoil sections.

Three references.

Formulæ for Stress Analysis of Circular Rings in a Monocoque Fuselage. (R. A. Miller and K. D. Wood, N.A.C.A. Tech. Note No. 462, 1933.) (5.45/28015 U.S.A.)

From authors' abstract.—In the stress analysis of fuselage bulkheads of approximately circular form and uniform cross section, complicated load systems acting on a ring are resolved into simpler systems, and formulæ for moment, axial force, and shear are given, with numerical examples.

Four references.

Aircraft—Landing Gear

Aerodynamic Effect of a Retractable Landing Gear. (S. J. de France, N.A.C.A. Tech. Note No. 456, 1933.) (5.515/28016 U.S.A.)

From author's abstract.—Measurements were made in the N.A.C.A. full-scale wind tunnel of the lift and drag characteristics of a Lockheed Altair aeroplane through the flying range of incidence, with the landing gear both retracted and extended.

Covering the wheel openings with carriage extended reduced the drag only by 2 per cent., with a lift coefficient of 1.0, a negligible effect on the take-off. Retracting the landing gear reduced the minimum drag of the complete aeroplane by 50 per cent. [The additional weight is not stated.]

One reference.

Airscrews

Adaptation of Screw Propeller Theory to practical Computations. (K. Schimamoto, W.R.H., Vol. 14, No. 21, 1/11/33, pp. 297-302.) (5.60/28017 Germany.)

The usual assumptions are made and standard formulæ are established. The results are expressed in functions of angles and offer certain advantages for computations, which are facilitated by curves and numerical tables.

Estimation of the Variation of Thrust Horse-Power with Air Speed. (S. Ober, N.A.C.A. Tech. Note No. 446, 1933.) (5.60/28018 U.S.A.)

In extension of Report No. 350, the characteristics of a conventional thin metal fixed pitch propeller are calculated on the assumption that they are functions of the single parameter V/nD.

Three references.

Measurement of Pressure Variations in the Neighbourhood of an Airscrew Disc. (Y. Yosida, Aeronautical Research Institute, Tokyo, Report No. 99, Vol. 8, No. 3.) (5.61/28019 Japan.)

The pressure variation was recorded by a condenser microphone, amplifier and oscillograph. A photograph shows the complete installation and a diagram shows the positions selected for measurement. Oscillograph records are reproduced and sketches show the average wave forms at the 13 different positions.

Amplitude is plotted against angular velocity for different blades and positions. Amplitude is also plotted against distance from the blade disc. The wave form undergoes heavy distortion with distance from the blade disc until the distance is large compared with the radius, after which the whole disc may be regarded as a source with an approximate sine wave distribution.

Three references.

Variable Pitch Airscrew. (W. G. Jennings, J.R.Aer.Soc., Vol. 38, No. 277, Jan., 1934, pp. 1-23.) (5.64/28020 Great Britain.)

The aerodynamical effects of varying the pitch diameter ratio are reviewed and illustrated by graphical representations of static thrust, rising thrust, range, maximum r.p.m. in a dive, etc., as functions of this parameter. The application of variable gears is also considered.

Definite aerodynamical advantages are obtained, but consideration of the disadvantages of weight and complication is left to airscrew and engine designers. An important discussion followed.

Recent Designs for Ships and Rudders Utilising Eddy and Slip Losses for Propulsion. (W. R. H., Vol. 14, No. 24, 15/12/33, pp. 347-350.) (5.644/28021 Germany.)

The devices discussed consisted principally of rings or tubes shrouding the propeller. At the same time a propulsion effect can be obtained by the reaction of the propeller jet on the rudder, if the latter is of suitable shape and placed correctly.

From the discussion it appears that although these devices often give beneficial results, there is no general agreement on underlying principles.

Experiments with a Counter-Propeller. (E. P. Lesley, N.A.C.A. Tech. Note No. 453, 1933.) (5.644/28022 U.S.A.)

Tests at Stanford University on a rotating two-bladed airscrew in conjunction with a fixed four-bladed counterscrew show an increase of about 2 per cent. in the efficiency over the full working range.

Instruments

Determination of the Density and Viscosity of Gases by the Schilling-Bunsen Apparatus. (W. Schiller, F.G.I., Vol. 4, No. 5, Sept./Oct., 1933, pp. 225-229.) (6.225/28023 Germany.)

The apparatus compares the time of discharge through a small orifice of equal volumes of two gases kept at the same pressure and temperature. Difficulties arise from variations in the discharge coefficient.

Methods of construction of small nozzles with a constant coefficient are given. The instrument can be used as a viscosimeter after simple calibration. An example shows a satisfactory degree of accuracy.

Ten references.

Apparatus for Measuring Waves. (W. Pabst, Z.F.M., Vol. 24, No. 21, 4/11/33, pp. 598-600, and No. 22, 28/11/33, pp. 616-619. D.V.L. Report No. 360.) 6.24/28024 Germany.)

A moored buoy, in the shape of a flat double cone, carries a water pressure registering apparatus at the end of a vertical cable, the length of which is adjustable to half the wavelength or more. The equations of motion for a two-dimensional wave in uniform depth are quoted from Lamb. The expression for the pressure gradient as a function of the depth is periodic with the wave, and is integrated to give the effective pressure at any point and in particular at the registering apparatus. Corrections are required for the finite depth of suspension and for the inertia of the whole apparatus under periodic wave forces.

Examples of errors are shown graphically for particular assumptions, and families of curves give corrections for any combinations of wavelength, cable length and depth. Examples of records are reproduced and the corresponding data are given in a table. A chart shows the Lübeck Bight in which the measurements were made.

Thermal Relay for Increasing the Sensitivity of Galvanometers. (Z.V.D.I., Vol. 77, No. 48, 2/12/33, p. 1290.) (6.35/28025 Germany.)

The reflected beam of a galvanometer falls on a thermocouple with two junctions connected by a bridge piece in a vacuum, which produce a current when the beam strikes the bridge piece asymmetrically. A small deflection of the first galvanometer produces a relatively large deflection in a second galvanometer.

One reference.

Theory of Airscrew Anemometers. (F.G.I., Vol. 4, No. 5, Sept./Oct., 1933, p. 257.) (6.40/28026 Germany.)

The effect of friction of the mechanism and of the air becomes serious at low air speeds. Expressions are developed with coefficients determined by calibration. The pitch of flat blades which gives the earliest response to small air currents is 40°, irrespective of number and size.

Two references.

Aircraft Power-Plant Instruments. (H. Sontag and W. G. Brombacher, N.A.C.A. Report No. 466, 1933, 57 pages.) (6.44/28027 U.S.A.)

About half the report deals with engine tachometers, of which the centrifugal and chronometric types are the most important. Considerable space is given to electric tachometers. Methods of calibration are described.

Thermometers include liquid filled, vapour pressure, electrical resistance and thermocouple types. Pressure gauges include Bourdon and electrical types. Calibration and performance are discussed. Supercharging pressure gauges are discussed separately. Fuel quantity gauges of float and hydrostatic pressure type and flow meters of indicating and recording type are considered and illustrated.

The report covers present U.S.A. practice.

Fifty-nine references.

Accurate Altitude Angles Determined by Periscope Sextant. (G. Förstner, Z.F.M., Vol. 24, No. 24, 28/12/33, pp. 680-684. D.V.L. Report No. 356.) (6.532/28028 Germany.)

The sextant is mounted with the object glass exposed above the cabin roof and cowled to reduce resistance. The rays from the object observed are reflected into a vertical tube with a horizontal eye piece. The field of view includes level and cross level bubbles, segments of the graduated altitude and azimuth circles

and of the compass card. Calibration on the ground showed errors of one-tenth minute in altitude and one-tenth degree in azimuth.

Observations in flight gave position fixes on a map, which were compared with determinations of the aeroplane's position upon the ground. The methods of reduction are stated briefly and numerical results are given in extensive tables. A systematic error of 15 ft. was found, and deviations lying between +65 ft. and −59 ft. The mean error was about ±3.8 ft., as compared with ±4.4 ft. in a hand sextant.

Three references.

Development in Echo Sounding Devices. (W. Kunze, Z.V.D.I., Vol. 77, No. 47, 25/11/33, pp. 1265-1267.) (6.62/28029 Germany.)

The article deals mainly with the design of the well-known "Atlas" apparatus for water sounding. Depth between 200 and 500 metres can be measured 23 times per minute with an accuracy of ±½ m. A record depth of 13,000 metres has been found in the Caribbean Sea. The sound took 17 seconds for the double journey.

Two references.

Investigation of Accelerations Imposed on Aircraft by Manœuvres and Gusts. (A. Guglielmetti, Riv. Aeron., No. 11, Nov., 1933, pp. 234-257.) (6.73/28030 Italy.)

A review is given of British and American work and the use of accelerometers is recommended in test flights of types subject to high accelerations.

Aircraft Flight

Experimental Determination of Moments of Inertia of Aeroplanes. (H. A. Soulé and M. P. Miller, N.A.C.A. Report No. 467, 1933, 15 pages.) (7.20/28031 U.S.A.)

The periods are affected dynamically by the virtual mass added by the surrounding air, and to a slight extent statically by the buoyancy and the air contained in the wings, body, etc. The standard formulæ of hydrodynamics for the virtual mass are plotted graphically for rapid computation of the effect of the wings regarded as plane laminæ.

The body offers greater difficulties, and an empirical factor was obtained by independent tests on a mock-up body. Effects of dihedral and gap were estimated and are exhibited graphically. Methods of suspension are described and a numerical example is worked out. Errors lie within ±2.5 per cent., ±1.3 per cent., ±0.8 per cent. for rolling, pitching and yawing moments of inertia.

Five references.

Problems on Stabilisation of Water and Aircraft. (W.R.H., Vol. 14, No. 24, 15/12/33, p. 345.) (7.50/28032 Germany.)

A development of the Frahm damping tank has led to the so-called "activated" stabilisation system. It is intended to give greater accuracy to artillery fire, especially on destroyers and small cruisers (up to 5,000 tons). The fundamental principle of resonance between the oscillating water in the tanks and the motion of the ship is retained, but the motion of the water is governed by air pressure under gyro control. The combination is stated to be superior to the direct stabilisation by large scale gyro.

Experiments have also been carried out in conjunction with the Italian Navy, employing a weight with a controlled movement along a curved track.

Devices for the stabilisation of aircraft have been investigated. They depend on a direction indicator regulating a servo motor which works the controls. Additional damping devices as used in ships are not utilised.

Study of Factors Affecting the Steady Spin of an Aeroplane. (N. F. Scudder, N.A.C.A. Tech. Note No. 468, 1933.) (7.62/28033 U.S.A.)

From author's abstract.—Data from wind tunnel tests on a model of the NY-1 aeroplane in steady spin showed that the important factors were mass distribution effects and aerodynamic effects.

Experimental data from various sources were available to verify nearly all the deductions resulting from the study of the curves.

In seeking to control the spin, the yawing moment equilibrium was found to offer the most promising field for research. The most serious unfavourable effect on the damping yawing moment of the tail is the blanketing of the vertical surfaces by the other parts of the tail.

Fifteen references.

Effect of Stabiliser Location upon Pitching and Yawing Moments in Spins—Tests with the Spinning Balance. (M. J. Bamber and C. H. Zimmerman, N.A.C.A. Tech. Note No. 474, 1933.) (7.72/28034 U.S.A.)

From authors' abstract.—A low-wing monoplane with the fin faired into the fuselage was tested for the effect of stabiliser location upon the pitching and yawing moments given by the tail surfaces in spinning attitudes.

The horizontal surfaces in normal location seriously reduced the yawing moment of fin and rudder, particularly at angles of attack of 50° or more; a forward or rearward location gave no consistent decided improvement. A lower location greatly increased the harmful shielding; a higher location decreased the shielding and interference effects, and even increasd the yawing moment at high angles of attack.

The stabiliser and elevator gave the largest pitching moment, in general, in the low and most rearward locations. High location gave feeble elevator pitching moments which vanished at angles of attack higher than 50°.

Seven references.

Effect of Split Trailing Edge Wing Flaps on the Aerodynamic Characteristics of a Parasol Monoplane. (R. N. Wallace, N.A.C.A. Tech. Note No. 475, 1933.) (7.72/28035 U.S.A.)

From author's abstract.—Tests were made in the N.A.C.A. full-scale wind tunnel on a Fairchild F-22 aeroplane with split trailing edge flaps, 90 per cent. of the wing span, and 20 per cent. of the wing chord.

With a flap setting of 59° the maximum lift was increased 42 per cent. and the range of available gliding angles from 2.7° to 7.0°. With flaps down the landing speed of the aeroplane is decreased without seriously affecting longitudinal balance, but the calculated climb and level flight performance is inferior. The take-off distance required to clear an obstacle 100 ft. high is not affected by flap settings from 0° to 20°, but is greatly increased by larger flap angles.

Two references.

Thurston Wing Tip Rotors. (A. P. Thurston, J.Roy.Aer.Soc., Vol. 38, No. 277, Jan., 1934, pp. 59-65, and No. 278, Feb., 1934, pp. 138-140.) (7.72/28036 Great Britain.)

Sketches show the rotor shaped as an auxiliary aerofoil, of constant section and camber in the shape of a lune, pivoted at the centre and capable of lying smoothly along the leading edge of the wing or of being raised and rotating approximately parallel to the plane of the wing. Test results show the removal of the drop in the lift curve above stalling incidence.

The author comments on the results in the official R.A.E. report B.A. 1083 and suggests general lines of development and application.

Thurston Wing Tip Rotors. (A. S. Hartshorn and C. Callen, J.R.Aer.Soc., Vol. 38, No. 278, Feb., 1934, pp. 141-161. R.A.E. Report B.A. 1083.) (7.72/28037 Great Britain.)

Lift was measured for 86 different arrangements and drag for 19 different arrangements of Thurston rotors. The latter are small cambered aerofoils, with no pitch, mounted at their centre on spindles at the wing tips, and auto-rotate in flight.

A mass of test figures is published, and, by selection of the most favourable positions, substantial increases in maximum lift are obtained, in favourable comparison with slots.

The paper is preceded by a commentary by Dr. Thurston with suggestions for practical applications.

Tests of Wings with Auxiliary Aerofoils. (F. E. Weick and R. Sanders, N.A.C.A. Report No. 477, 1933, 20 pages.) (7.72/28038 U.S.A.)

Half-span wings with an end plate and attached auxiliary aerofoils of three different sections and four different chord lengths were tested in the five-foot vertical channel. The auxiliary aerofoils are mounted forward of the leading edge. The lift, drag, and moment coefficients are tabulated and plotted against incidence in groups for comparison. The lift is increased slightly with the increased area, and in the best positions the L/D ratio is increased.

Elaborate diagrams show curves of C_L, L/D, etc. No very striking results were obtained.

Three references (to authors' previous work only).

Wind Tunnel Tests on Model Wing with Fowler Flap and Specially Developed Leading Edge Slot. (F. E. Weick and R. C. Platt, N.A.C.A. Tech. Note No. 459, 1933.) (7.72/28039 U.S.A.)

From authors' abstract.—A special form of slot was developed in conjunction with the Fowler flap and the best combinations increased the maximum lift coefficient from 3.17 to 3.62. The minimum drag coefficient with both devices retracted was increased in about the same proportion.

The special slot, with or without the Fowler flap, gave higher values of the maximum lift coefficient than slots of conventional form, with proportional increase in the minimum drag coefficient.

Four references.

Effect of Partial-Span Split Flaps on the Aerodynamic Characteristics of a Clark Y Wing. (C. J. Wenzinger, N.A.C.A. Tech. Note No. 472, 1933.) (7.72/28040 U.S.A.)

From author's abstract.—Aerodynamic force tests were made in the N.A.C.A. 7 ft. × 10 ft. wind tunnel on a model Clark Y wing with a 20 per cent. chord split flap deflected 60° downward to determine the effect of partial-span split flaps, located at various positions along the wing span, on the aerodynamic characteristics of the wing-and-flap combination.

The results are given in the form of curves of lift, drag and centre of pressure.

Five references.

Effect of Slots and Flaps on Lateral Control of a Low Wing Monoplane as Determined in Flight. (H. A. Soulé and J. W. Wetmore, N.A.C.A. Tech. Note No. 478, 1933.) (7.72/28041 U.S.A.)

From authors' abstract.—Maximum angular accelerations in roll and yaw produced by sudden application of the ailerons, and maximum accelerations in yaw produced by sudden application of the rudder during gliding flight were recorded for various wing arrangements.

The full span slots and the flaps had about equal influence on the aileron rolling moments. In the range covered by the tests the effectiveness of the controls was appreciably reduced by the wing tip slots. The adverse yawing moment of the ailerons experienced at the large lift coefficients obtained with the flaps was appreciably less than at similar lift coefficients with full span or wing-tip slots. The yawing moments produced by the rudder were slightly affected by the auxiliary devices. The aeroplane was found to be laterally unstable with all combinations tested.

Four references.

Engines—Thermodynamics

The Radiation of Luminous and Non-Luminous Flame of Natural Gas. (A. Schack, F.G.I., Vol. 4, No. 5, Sept./Oct., 1933, pp. 255-256.) (8.10/28042 Germany.)

Experiments were carried out in a furnace, with flames varying between 25 and 89 cm. in thickness, at about 1,400°C. With a non-luminous flame the ratio of observed radiation per sq.m.hr. to black body radiation ranged from 0.05 to 0.2. With luminous flames the ratio may approach 0.7. The gas becomes more opaque and this may seriously affect the quantity of radiation from the walls to the centre of the furnace.

Five references.

Fuel Vaporisation in the Diesel Engine. (L. Richter, Z.V.D.I., Vol. 77, No. 45, 11/11/33, p. 1204.) (8.13/28043 Germany.)

The results of the N.A.C.A. report No. 435 indicate that combustion in Diesel engines is largely controlled by previous vaporisation of the fuel. This is contrary to the generally accepted view that combustion starts on the liquid surface.

Further experiments are recommended before accepting the implications of the American experiment.

One reference.

The Rate of Heating of Wires by Surface Combustion. (W. Davies, Phil. Mag., Vol. 17, No. 11, Feb., 1934, pp. 233-251.) (8.13/28044 Great Britain.)

Combustion in the gas phase begins on the surface of the wire, but by the time the temperature of the gas in the immediate neighbourhood of the wire has been raised to the ignition point, the concentration of combustible gas in this region has been reduced to such an extent that it will not propagate the flame. The wire must, therefore, be heated considerably above the ignition temperature before a propellant flame is produced.

Six references.

Influence of Natural Oscillation of Burning Gas Mixtures on their Speed of Combustion. (H. Nielsen, F.G.I., Vol. 4, No. 6, Nov./Dec., 1933, pp. 300-307.) (8.13/28045 Germany.)

Experiments with pentane mixtures in a cylindrical bomb showed the visual increase in flame speed as combustion proceeds. The pressure rise was measured piezo-electrically and the flame speed by ionisation. Gas vibration was recorded by a sensitive valve amplifier with the quartz indicator.

A definite connection is traced between amplitude of gas vibration and flame speed. It appears that a phenomenon similar to that existing in " singing flames " occurs, the gas vibration being the cause of the increased rate of energy release and not the result. The vibration was suppressed and the flame speed lowered by lining the walls of the bomb with glass wool.

Seven references.

The Supposed Intervention of Steam in Hydrocarbon Combustion. (W. A. Bone and J. Bell, Proc. Roy. Soc., Vol. 144, No. A.852, 29/3/34, pp. 257-266.) (8.13/28046 Great Britain.)

From a review of existing data and explosion photographs of acetylene and ethylene, both dry and moist, it is concluded that the formation of steam does not affect the reactions and that the oxidation is direct.

Three references.

Flame Temperatures in CO/Air Mixtures. (W. T. David and J. Jordan, Phil. Mag., Vol. 17, No. 110, Jan., 1934, pp. 172-180.) (8.13/28047 Great Britain.)

Flame temperature during the pressure period of CO explosives in bombs was measured from records by a Pt-Rho resistance thermometer .0005 inches in diameter. The results are considerably lower than those calculated from the best values of specific heat and dissociation. The authors are satisfied that radiation losses cannot account for the difference, which must be due to some abnormality in the freshly-burnt gas.

Eight references.

Influence of Pressure on Flame Spectra. (W. A. Bone and F. S. Lamont, Proc. Roy. Soc., Vol. 144, No. A.852, 29/3/34, pp. 250-250.) (8.13/28048 Great Britain.)

With H_2 and CO mixtures, as the pressure is increased to 100 atmospheres, direct oxidation of CO progressively replaces indirect oxidation.

Three references.

Thermo Elements for High Temperatures. (A. Schulze, Z.V.D.I., Vol. 77, No. 46, 18/11/33, pp. 1241-1242.) (8.14/28049 Germany.)

Up to 1,500°C. the Pt-Pt.Rho couple of Chatelier is generally used. For higher temperatures couples made of Ir-Ir. Ruth. (up to 1,800°C.) and Ir-Rho.Ir (up to 2,000°C.) have been developed. Magnesium and thorium oxides are the most suitable materials for protective tubing at very high temperatures.

Five references.

N.A.C.A. Chamber Gas-Sampling Valve—Some Preliminary Test Results. (J. A. Spanogle and E. C. Buckley, N.A.C.A. Tech. Note No. 454, 1933.) (8.15/28050 U.S.A.)

A gas-sampling valve, inertia-operated, for procuring samples at identical points in successive cycles has been used to investigate the CO_2 content of gases taken from the quiescent combustion chamber of a high-speed compression-ignition engine operating with two different multiple-orifice fuel-injection nozzles. The analysis of the gas samples shows that quiescence is maintained in the chamber during combustion.

Seven references.

Relation of Hydrogen and Methane to Carbon-Monoxide in Exhaust Gases from Internal Combustion Engines. (H. C. Gerrish and A. M. Tessman, N.A.C.A. Report No. 476, 1933.) (8.15/28051 U.S.A.)

The hydrogen in the exhaust gases is in constant proportion to the carbon monoxide, between .3 and .5, according to the fuel. The methane content is small and apparently independent of the mixture strength. No satisfactory explanation is available.

Seven references.

Engines—Design and Performance

Effect on Engine Performance of Change in Jacket-Water Outlet Temperature. (E. A. Garlock and G. Ellis, N.A.C.A. Tech. Note No. 476.) (8.20/28052 U.S.A.)

Authors' abstract.—Tests made on a Curtiss D.12 engine in the Altitude Laboratory at the Bureau of Standards show the following effects on engine performance of change in jacket-water outlet temperature:—

(1) Friction at all altitudes is a linear function of jacket-water temperature, decreasing with increasing temperature.

(2) The brake horse-power below an altitude of about 9,000 ft. decreases, and at higher altitudes increases, with increasing jacket-water temperature.

(3) The brake specific fuel consumption tends to decrease, at all altitudes, with increasing jacket-water temperature.

(4) The percentage change in brake power output is roughly equal to the sum of the percentage changes in volumetric efficiency and mechanical efficiency.

Six references.

Developments in High Powered Aircraft Engine. (G. D. Angle, Aero Digest., Vol. 23, No. 4, Oct., 1933, pp. 41-44, and No. 5, Nov., 1933, pp. 46-47.) (8.20/28053 U.S.A.)

Engines with outputs exceeding 800 h.p. are being developed in Italy and France. Great Britain formerly held the lead, but more attention is now being given to reliability than to high output for individual engines.

In 1927 the U.S.A. Packard firm built a 24-cylinder X engine of 1,200 h.p., which did not get into production. At the moment manufacturers in America appear to keep within 800 h.p.

The Development of the Air-Cooled Engine. (A. H. R. Fedden, J.R.Aer.Soc., Vol. 38, No. 279, March, 1934, pp. 169-234.) (8.20/28054 Great Britain.)

The author is of the opinion that aero engines for sport, civil work and military purposes will mainly be of the four-stroke cycle, with electric ignition, using petrol as fuel. Improvements in fuel and oils, valves and other design features will improve the volume-power output. The air-cooled engine will maintain and extend its position in comparison with water-cooled engines.

Descriptive technical data are given of materials, design details, assembly and performance. The paper may be regarded as a statement of the point of view of the designer of successful air-cooled engines. In the discussion the claims of water cooling and higher temperature liquid cooling were stated. Paper and discussion give a useful exposition of current design and of prospective lines of advance.

Thirty-three illustrations.

The Scavenging Process of Two-Stroke Engines. (W. Lindner, Forschungsheft, No. 363, Nov./Dec., 1933, pp. 9-22.) (8.21/28055 Germany.)

The air paths in a model during scavenging are made visible by finely powdered Mg.O. Photographs show generally the presence of a central vortex of intensity governed largely by the shape and inclination of the scavening air port. In a working engine the scavenging process is followed from point to point by a sampling valve and similar conclusions are reached.

Fifteen references and 30 illustrations.

Investigation on High Speed Superchargers of the Eccentric Vane Type. (H. J. Venediger, Autom. Tech. Zeit., Vol. 36, No. 23, 10/12/33, pp. 583-597, and No. 24, 25/12/33, pp. 619-622.) (8.235/28056 Germany.)

The two types of superchargers were fitted with external and internal blade control members respectively. The Zoller type has blades fitted with shoes which slide on internal eccentric bosses. The Powerplus type has a blade control drum which surrounds the blades and is driven at the same speed as the rotor by a ring drive.

The maximum pumping efficiencies are approximately equal. The Powerplus type is more robust and can be operated at higher speeds, especially in the larger sizes. For general applications improved pumping efficiency at low speeds is required.

Six references.

Engines Fitted with Superchargers. (D. Cosci, L'Aerotecnica, Vol. 13, No. 11, Nov., 1933, pp. 1451-1478.) (8.235/28057 Italy.)

The operation and characteristics of the positive and centrifugal type of supercharger are described. The Roots type of blower fitted to the Alfa Romeo D.2 radial engine is shown in an illustration.

Research Problems in Power Plants for Ships. (Z.V.D.I., Vol. 77, No. 47, 25/11/33, p. 1270.) (8.25/28058 Germany.)

Consideration is given to Diesel-electric power transmission with synchronous electric motors of new design.

As regards design questions, the V.D.I. are collecting available information on the stress distribution round notches, in keyways and constructional elements, and on the effect of surface conditions on fatigue limits. Special attention is being given to the stresses arising in the manufacture of turbine rotors, and the subsequent effect of corrosion.

Two references.

The Compression Ignition Engine. (C. B. Dicksee, J.Roy.Aer.Soc., Vol. 38, No. 277, Jan., 1934, pp. 24-45.) (8.25/28059 Great Britain.)

A review is given of developments in the compression-ignition engine and representative data and performance are given graphically. A number of problems of detail are discussed, in particular the type of injection spray and the shape of the combustion chamber.

Comparison with the petrol engine shows that further advances are required before aircraft designers can consider application of compression-ignition engines to aeronautics. The author is hopeful that this will ultimately come about.

Increasing the Air Charge and Scavenging the Clearance Volume of a Compression Ignition Engine. (J. A. Spanogle, C. W. Hicks and H. H. Foster, N.A.C.A. Report No. 469, 1933.) (8.25/28060 U.S.A.)

Experiments were carried out on a single-cylinder four-stroke injection engine with boost pressures up to eight inches of mercury. Both normal valve timing and one giving 145° overlap were employed. The overlap leads to a considerable increase in air consumption, since some of the air is employed in scavenging the exhaust products.

After making allowance for work absorbed in the blower, the scavenged engine gave about 10 per cent. more power than the unscavenged engine for the same amount of boost (about 4 lb. per sq. in.), with a slightly better specific fuel consumption. The advantage of valve overlap appears to be limited to relatively low boost pressures.

Eleven references.

Investigation on the Compression Ignition Engine with Separate Air Chamber. (K. Neumann, F.G.I., Vol. 4, No. 6, Nov./Dec., 1933, pp. 268-279.) (8.25/28061 Germany.)

In the well-known two-stage ignition engine, combustion starts in the so-called pre-combustion chamber into which the fuel is injected. The combustion is completed in the main cylinder.

In the engine described combustion is started in the main cylinder, the function of the air chamber being to produce a vigorous eddy during the initial stage of the expansion stroke. The eddy may be entirely formed by the re-transfer of air compressed during the previous stroke or in part by a certain amount of combustion in the air chamber of fuel from the main cylinder. In the latter case the effect of the eddy is modified. The large number of possible intermediate constructions obscures the patent position.

The author concludes that the best results are given by high compression ratio and large capacity of the air chamber producing a vigorous " suction eddy " during the expansion stroke.

Engines of this type are well adapted to high-speed work, and their use in mobile units is increasing.

Six references.

Development of Diesel Aviation Engines. (F. A. F. Schmidt, Z.V.D.I., Vol. 77, No. 44, 4/11/33, pp. 1183-1187.) (8.25/28062 Germany.)

The volumetric output in horse-power per litre is shown graphically against volume, as a mean of 140 carburettor air engines and 12 Diesel air engines. Total weight, mean effective pressure and mean piston speed are also shown graphically on a stroke volume basis.

Indicator diagrams of two Diesels with different types of injection are plotted for comparison. Four photographs are reproduced showing Junkers, Rolls-Royce, Bristol, and Hispano-Suiza Diesel air engines, the two former water-cooled, the two latter air-cooled.

Twelve references.

Direct Driven Diesel Locomotive. (A. Lengen, Forschungsheft, No. 363, Nov./Dec., 1933, pp. 1-8.) (8.252/28063 Germany.)

For starting and low power, the double-acting two-stroke engine is supplied with compressed air at 300 lb. per sq. in. An auxiliary hot wire ignition system is fitted, and a supply of low-pressure fuel and air is regulated to maintain nearly constant pressure through the greater part of the expansion stroke. As engine speed and load increase, the air and low-pressure fuel supply is diminished and the high-pressure fuel injection system started. The engine passes through a state of supercharging, and finally functions as a normal Diesel.

The advantage claimed for this system is the small air consumption when starting and on low load, since the heat of the injected fuel makes the air drive more efficient.

Results on service are awaited.

Electrically Heated Sparking Plugs. (B. v. Lengerke, Autom. Tech. Zeit., Vol. 36, No. 23, 10/12/33, p. 592.) (8.283/28064 Germany.)

A plug is shown fitted with an electric heating device to prevent deposition of fuel on the insulator and electrode.

Sulzer Single Tube Steam Generator. (Prof. A. Stodola, Z.V.D.I., Vol. 77, No. 46, 18/11/33, pp. 1225-1232.) (8.294/28065 Germany.)

The tube diameter is 40 mm., length 1,300 metres, working pressure 100 atmospheres. Feed water enters at 150°C., 130 atmospheres, and leaves as superheated steam at 400°C., 100 atmospheres. The pressure drop along the tube ensures active circulation and high heat transfer.

Over 7,000 kg. of water are evaporated per hour, giving 24 kg. of steam per hour per square metre of heating surface.

Two references.

Steam Propulsion for Aircraft. (F. W. Ellyson, Flugsport, Vol. 25, No. 20, 27/9/33, pp. 429-431.) (8.294/28066 Germany.)

According to a report by American engineers, a two-cylinder compound V engine of 3-in. stroke and 2-in. and 5¼-in. bore, supplied with steam at 1,200 lb. per sq. in. pressure, gives 180 h.p. at 1,625 r.p.m., engine weight 180 lb. The boiler is heated with oil fuel, consists of a single tube 500 ft. in length, and, with accessories, weighs 150 lbs. No details are given of condensing plant and water consumption.

Three photographs show the plant as installed in a U.S.A. aeroplane.

Engines—Design and Strength of Components

Bending Loads on Connecting Rods. (O. Heck, Ing. Arch., Vol. 4, No. 6, Dec., 1933, pp. 596-605.) (8.32/28067 Germany.)

Kinematical relations are obtained in the usual way by trigonometric and algebraic expansions in series.

The dynamical and elastic equations are expressed and lead to integral equations for the determination of the bending stresses. The cores of the equations are expressed in comparatively simple algebraic forms and numerical solutions are worked out for particular cases.

Torsional Vibration of Aircraft Engine Crankshafts. (W. G. Lundquist, Aeron. Eng., Vol. 5, No. 3, July/Sept., 1933, pp. 133-139.) (8.36/28068 U.S.A.)

Torsional vibrations of several radial engines and a 12-cylinder V engine are compared. The damping factor is of the same order. Crankshaft vibration when it does occur is usually more serious in the radial, the amplitude of the disturbing harmonic being greater in the operative range. The best cure is proper dimensioning of the parts and good distribution of mass.

Vibration dampers are not recommended. They do not eliminate the source of the trouble, are heavy and liable to faulty adjustment.

New Piston Designs. (Z.V.D.I., Vol. 77, No. 49, 9/12/33, p. 1310.) (8.38/28069 Germany.)

The upper part of the piston, of light alloy, has an insert of Niresist cast iron, with approximately the same coefficient of thermal expansion, in which two of the ring grooves are cut. Freedom from differential expansion troubles has increased the piston's life, notably in a small high-speed Diesel for mobile work.

Two references.

Gas Tightness and Gumming of Piston Rings. (N. Champsaur, Pub. Sc. et Tech., No. 31, 1933.) (8.38/28070 France.)

Gas leakage past the piston rings is measured by connecting the engine crankcase breather to a small gas meter. Details are not given, nor is it clear how leakage through the crankcase bearings is allowed for.

The author states that gumming is indicated by a gradual increase in leakage long before variations in power, temperature, etc., are sensible.

Engines—Cooling

Experiments on the Cooling of Hot Bodies by a Current of Air. (P. Vernotte and E. Blouin, Pub. Sc. et Tech., No. 36, 1933.) (8.40/28071 France.)

Air flows from a tank at four atmospheres pressure to a tank at lower pressure through aluminium tubes of various sections heated electrically. Air speeds up to 120 m. per sec. were obtained. The heat transfer coefficient is approximately a linear function of the speed and reaching .01 cal/cm²/sec. at maximum speed.

Dissipation of Heat from Hot Wires and Pipes in a Current of Air. (R. Hilpert, F.G.I., Vol. 4, No. 5, Sept./Oct., 1933, pp. 215-225.) (8.40/28072 Germany.)

The wires and tubes were electrically heated, with elaborate precautions to ensure uniform temperature distribution. The range of diameters varied from 0.2 mm. to 90 mm. in conjunction with an air speed variation from 2 to 30 m. per sec., this gives a range of Reynolds numbers from 2 to 10^5. Tables and curves give the variation of the heat transfer, which generally decreased with increasing R from 3,000 K cal/m^2h°C. for small wires to less than 20 for the largest body examined.

Eleven references.

Heat Flow through Piston and Piston rings in a Diesel Engine. (F. Salzmann, F.G.I., Vol. 4, No. 4, July/Aug., 1933, pp. 193-198.) (8.40/28073 Germany.)

Of the total heat received by the piston, 67 per cent. is transmitted to the cylinder through the piston rings, 24 per cent. through the skirt and oil film, and 9 per cent. was carried off by leakage-air and oil splash.

Thirteen references.

Influence of Wall Roughness on Heat transfer to Water. (W. Pohl, F.G.I., Vol. 4, No. 5, Sept./Oct., 1933, pp. 230-237.) (8.40/28074 Germany.)

The author determined both the resistance and the heat transfer coefficient of steel, copper, and cast iron tubes with varying degrees of roughness of the internal surface. The tube carried water at app. 12°C., the wall being kept at app. 20°C. The heat transfer coefficient was found to diminish with increase of surface roughness, although the resistance coefficient increased in disagreement with semi-empirical expressions in current forms.

Established expressions for the heat transfer coefficient in smooth pipes are in general agreement with the author's results for smooth pipes.

Thirteen references.

Reduction of Drag of Radial Engines. (E. Everling, Z.V.D.I., Vol. 77, No. 44, 4/11/33, pp. 1197-1200.) (8.426/28075 Germany.)

A brief descriptive account is given of the forms of cowling in use, illustrated by eleven representative photographs of cowled engines mounted on aeroplanes.

Six references.

Engines—Lubricants and Lubrication

The Acidity of Castor Oil and its Neutralisation by Organic Base. (S. Montelucci, L'Aerotecnica, Vol. 13, No. 11, Nov., 1933, pp. 1479-1484.) (8.540/28076 Italy.)

The author suggests that the use of trietanolamine soaps as a castor oil " dope " reduces the acidity and gumming tendency of the oil and increases its lubricating quality.

One reference.

Research on the Spread of Castor Oil and Various Glycerides on the Surface of Water. (C. Bouhet and R. Lafont, Pub. Sc. et Tech., No. 33, 1933.) (8.540/28077 France.)

The surface tension of the film is measured by a torsion balance. The lubricating value appears to be intimately connected with the mean size of molecule, and increases with the molecular spread of the film on the water surface.

Colloidal Graphite as an Addition to Lubricating Oils. (E. Schida, Autom. Tech. Zeit., Vol. 36, No. 21, 10/11/33, pp. 527-531.) (8.540/28078 Germany.)

The experiments were carried out on a small four-stroke engine of 250 cc. capacity. Torque curves were taken with the oil supply cut off. With ordinary lubricant the engine seized after about eight minutes. The addition of colloidal graphite to the oil delayed the moment of seizure, especially if the engine had previously been " run in " on the mixture.

It is concluded that the graphite forms a film on the cylinder which has lubricating properties and enables the engine to continue running after failure of the oil supply for some time (roughly 14 minutes). The seizure is also less severe.

Influence of Anti-Friction Metals on Lubricants. (Fournery, L'Aéron., No. 173, Oct., 1933, pp. 232-233.) (8.540/28079 France.)

The mounting of the experiments and the run of the results are shown qualitatively in sketches, which show the thickness of the lubricating film as a decreasing function of the load and an increasing function of the bearing speed.

Engines—Fuels

Report on the 16th General Meeting of the Fuel Association, Berlin. (A. Sander, Autom. Tech. Zeit., Vol. 36, No. 24, 25/12/33, pp. 623-625.) (8.6/28080 Germany.)

The aim of the Association is to render Germany as independent as possible of foreign fuel supplies. The manufacture of fuel suitable for carburettor and injection engines from coal is therefore of paramount importance. The two-stage ignition engines and the air chamber engines are less sensitive to the grade of fuel available and are being actively developed. Experiments have been carried out with compressed methane and hydrogen.

Oil Production in Germany. (O. Zaepke, Z.V.D.I., Vol. 77, No. 52, 30/12/33, pp. 1374-5.) (8.6/28081 Germany.)

In 1932 229,000 tons of oil were produced, mostly from very deep bore holes. The technical difficulties are described and special attention is given to the conservation of natural gas.

Five references.

Performance of a Fuel Injection Spark Ignition Engine Using a Hydrogenated Safety Fuel. (O. W. Schey and A. W. Young, N.A.C.A. Report No. 471, 1933.) (8.602/28082 U.S.A.)

Injection at an average pressure of 5,000 lb. per sq. in. through five holes controlled by a spring loaded needle valve, started approximately 90° after T.D.C. on the suction stroke and lasted for about 90° crank angle. Combining the fuel injection with scavenging and mild boost at high compression ratio, a brake m.e.p. of 175 lb. per sq. in. was maintained for a consumption of .5lb. of safety fuel per b.h.p. hour.

In the unmodified engine the specific fuel consumption with hydrogenated fuel was about 10 per cent. greater than with petrol for the same power output.

Starting is difficult with the safety fuel. Satisfactory control requires accurate timing between the throttle and injection pump.

Engine Performance with a Hydrogenated Safety Fuel. (O. W. Schey and A. W. Young, N.A.C.A. Tech. Note No. 466, 1933.) (8.602/28083 U.S.A.)

From authors' abstract.—Tests were made on a single-cylinder universal test engine at compression ratios of 5.0, 5.5 and 6.0, with a fuel injection system, and one with a carburettor using gasoline for comparative performance.

The b.m.e.p. obtained with safety fuel in an injection system is slightly higher than with gasoline and a carburettor, but the fuel consumption is higher. The idling test was satisfactory. Starting was difficult with a cold engine, but not when the jacket water was hot. The use of the safety fuel should eliminate crash fires.

Four references.

Wood Gas as a Fuel for Light Oil Engines. (G. Kuhne, Z.V.D.I., Vol. 77, No. 48, 7/12/33, pp. 1293-1294.) (8.604/28084 Germany.)

A wood gas has been produced with a calorific value of approximately 1,300 kcal. per cubic metre, or 590 kcal. per cubic metre of combustible mixture, which is seriously less than the 830 kcal. per cubic metre of benzole mixture.

The difference can be partly made up by supercharging. With 5 lb. per sq. in. boost pressure a lorry engine which gave 52 h.p. with benzole gave 45 h.p. with wood gas, after allowing for the horse-power absorbed by the blower.

Two references.

The Use of Infra Red Absorption Spectra in the Study of the Constituents of Petrol. (J. Lecomte and P. Lambert, Pub. Sc. et Tech., No. 34, 1933.) (8.640/28085 France.)

The infra red absorption bands over the range 6μ to 16μ are measured by a recording thermopile. Most of the usual ring compounds and their derivatives are identified by their characteristic bands. The method is useful in examining small quantities.

The Importance of Auto-Ignition Lag in Knocking. (E. S. Taylor, N.A.C.A. Tech. Note No. 452, 1933.) (8.645/28086 U.S.A.)

In practice, knocking is caused by auto-ignition of the last part of the charge to burn. All fuels will knock if kept at a high temperature for a sufficient time.

Favourable fuel characteristics are long time lag of auto-ignition at high temperature, giving a wide range of running conditions, within which normal combustion of the whole fuel takes place.

Seven references.

Engines—Couplings

Shaft Drives for Airship and Aeroplane Propellers. (J. L. Goldthwaite, Aeron. Eng., Vol. 5, No. 3, July/Sept., 1933, pp. 129-132.) (8.765/28087 U.S.A.)

Long shafts require perfect balancing to prevent deflection at speed. Satisfactory flexible couplings used on the American airship " Akron " are described.

Reference is made to a composite coupling link composed of a loop of steel wire embedded in rubber. Short splines in shafts facilitate inspection of a detail which requires great care.

Armament

The Bombing of Reservoirs in Wartime. (Rougeron, Rev. F. Aer., No. 52, Nov., 1933, pp. 1203-1208.) (9.3/28088 France.)

A direct hit is not necessary for vital damage to containing walls. An underwater explosion within 100 ft. of the wall will probably wreck it. A bomb dropped from a fast machine flying at a low altitude will travel under water in the direction of the target with corresponding latitude in the accuracy of release.

Four references.

The Gehrlich 35 25 mm. Aircraft Machine Gun. (Flugsport, Vol. 25, No. 26, 20/12/33, p. 559.) (9.11/28089 Germany.)

The barrel is cylindrical internally for some distance at the root and then tapers from 35 mm. to 25 mm. The projectile of 25 mm. diameter is fitted with two collars of 35 mm. diameter of soft material, which are flattened by the choke and give a muzzle velocity stated to exceed 5,300 ft. per second.

Production of Very High Temperatures and Pressures. (C. Ramsauer, Phys. Zeit., Vol. 34, No. 24, 15/12/33, pp. 890-894.) (9.59/28090 Germany.)

A photograph shows two rifle barrels facing each other. A shot fired from one enters the other and compresses the air adiabatically up to the point of zero motion and maximum pressure and temperature. The initial velocity is measured by a cinematic camera and details of the films are reproduced.

The density, pressure and temperature are calculated for argon, nitrogen and carbon dioxide, for four initial velocities, the latter giving $\rho = 19 \times 10^4$ gr./cm.^{3} $p = 32 \times 10^9$ dynes/cm. (200 tons per sq. in.) $T = 89 \times 10^3$ degrees C.

Three references.

Materials—Characteristics, Defects and Treatment

Precision High Power Metallographic Apparatus. (F. F. Lucas, Bell Tele. G-771, 1933.) (10.1/28091 U.S.A.)

Details are given of the design, construction and operation of a metallographic apparatus with a resolving process giving clear definitions up to 6,000 diameter magnification. Objectives corrected for infinite tube length are superior to those corrected for a fixed tube length of 190 mm. The use of monochromatic light allows of further improvement in the objective.

Five references.

Method of Testing Hardness. (M. le Rolland, L'Aéron., No. 173, Oct., 1933, pp. 229-230.) (10.101/28092 France.)

A pendulum is supported by a ball bearing which rests on the surface to be tested. The diameter of the (circular) area of contact is in inverse proportion to the change in the period of the pendulum.

Extreme simplicity and accuracy is claimed and the absence of permanent strain is an obvious advantage over the Brinell test. Details of the mounting of a test are given.

Notes on the Increase of Fatigue Strength by Surface Pressure. (A. Thum and O. Föppl, Z.V.D.I., Vol. 77, No. 50, 10/12/33, pp. 1335-1337.) (10.104/28093 Germany.)

The authors agree on the beneficial effect of surface pressure treatment on fatigue strength, but disagree in their explanation. Thum and his collaborator attribute the effects to residual stresses in the material, which reduce the subsequent fatigue stresses. Föppl attributes the effects to a hardening of the surface layer accompanied by a re-orientation of surface molecules.

Twelve references.

Fatigue Strength Under Vibrating Load. The Effect of Corrosion and Preliminary Surface Pressure Treatment. (O. Föppl, O. Behrens and T. Dusold, Z. Metallk., Vol. 25, No. 11, Nov., 1933, pp. 279-282.) (10.104/10.245/28094 Germany.)

Torsional and bending loads were applied to test pieces of high grade alloy steels, and one of pure nickel immersed in a current of water.

In all cases preliminary surface pressure treatment reduces the corrosion and increases the fatigue strength, especially under bending stresses.

Six references.

Rubber Protection of Propeller Shafts Against Corrosion. (Z.V.D.I., Vol. 77, No. 51, 23/12/33, p. 1363.) (10.125/28095 Germany.)

Japanese experiments indicate that a good protection is obtained on ships by winding the propeller shaft with rubber strips, subsequently vulcanised. The weight and cost are relatively small.

The Use of Light Alloys in Ship Construction. (Z.V.D.I., Vol. 77, No. 47, 25/11/33, pp. 1270-1271.) (10.230/28096 Germany.)

Calculation shows that a saving in weight amounting to 1,200 tons results in the case of the ship "Arcone," by using a combined steel and light alloy construction for the upper structure of the ship. Rolling and pitching are thus considerably reduced. Without going to extremes weight can be saved by the use of light alloy for internal fittings, ventilating shafts, doors and furniture.

Electro-chemical oxidation against corrosion has been improved by subjecting the porous oxide layer to a condensation process.

Thermal Resistance and Hardness of Different Al. Alloys. (A. v. Zeerleder, Bosshard and Irmann, Z. Metallk., Vol. 25, No. 12, Dec., 1933, pp. 293-299.) (10.231/28097 Germany.)

Experiments carried out on pure aluminium and various alloys show the importance of preheating for various periods for the mechanical properties. It is essential that experimental conditions be accurately defined during annealing and hardening if stability of the product is to be assured.

Eleven references.

The Casting of Magnesium. (A. Caillon, Pub. Sc. et Tech., No. 32, 1933.) (10.232/28098 France.)

The author recommends the use of three fluxes in succession :—

1. During melting the usual sodium carnalite.
2. A flux containing Bo as well as Mg and BaF_2 to remove the chlorine.
3. Flux consisting of B_2O_3 and $Na_2B_4O_7$ for the final casting.

Seventy illustrations.

Fatigue of Materials in Aircraft and Engines. (K. Matthaes, Z.F.M., Vol. 24, No. 21, 4/11/33, pp. 593-598, and No. 22, 28/11/33, pp. 620-626. D.V.L. Report, No. 337.) (10.245/28099 Germany.)

Failing load is plotted against number of reversals for five metals or alloys and for spruce, and elastic coefficients are given in a table.

The ratio of static and fatigue failing loads are plotted from selected experiments and, in general, lie in narrow angular sectors with an angular variation of about 20 per cent. Test specimens are carefully finished and polished. Actual working materials show irregularities of surface finish arising in the course of manufacture, which in general lower the ultimate strength.

A table is given of ultimate strength of manufactured parts of different materials showing the observed reduction in comparison with test pieces. The influence of the fibrous structure and of manufactured shape are discussed. Light metals show differences, which are considered separately. Surface hardening, corrosion and concentration of stress are also discussed. The general considerations are applied more particularly to structural elements and to bolted, screwed and riveted joints.

The general impression conveyed by the paper is that careful attention to the points discussed may lead to notable improvements in reliability, even under apparently higher stresses, with materials already available and in general use. A note is added referring to similar work done by R. E. Petersen.

Thirty-one references.

Corrosion of Magnesium Alloys. (J. D. Bengough and L. Whitby, Aire. Eng., Vol. 6, No. 59, Jan., 1934, pp. 7-12.) (10.262/28100 Great Britain.)

An account is given of the behaviour of specimens exposed to a variety of conditions, with quantitative figures of the rate of formation of corrosion products and their composition.

Protective coats are formed by dipping in solutions and more than 500 solutions tried by the authors and many by other experimenters have come under examination. Of these, only two so far are considered as effective, the alum-dichromate process and the selenium process.

Specifications are given of various selenium dips and photographs show the comparative protection afforded by this and by other methods. A marked superiority of the selenium processes is indicated by the 21 photographs reproduced.

Specifications of treatments and many other useful details of technical information are given.

Twelve references.

The Assembly of Wood Structures. (M. Monnim, Pub. Sc. et Tech., No. 37, 1933.) (10.400/28101 France.)

The author is convinced that under proper supervision wood is superior to all the materials weight for weight. Certain precautions must be taken in assembling the bolts and ferrules. Later reports will give methods of calculation.

The Structure of Timbers. (F. W. Jane, J.Roy.Aer.Soc., Vol. 38, No. 277, Jan., 1934, pp. 46-58.) (10.400/28102 Great Britain.)

The properties of a large variety of timbers are briefly discussed in relation to their use. The applications range somewhat at random from battleships to cigar boxes, but the systematic exposition of principles is worthy of study by timber users.

Types of cellular and fibrous structure are shown in sketches.

Thirteen references.

Analysis of Torsional Tests on Timber Spars. (H. Hörig, Ing. Arch., Vol. 4, No. 6, Dec., 1933, pp. 570-576.) (10.400 Germany.)

The anisotropic character of timber introduces complications into the elastic equations. The simplifications introduced by assuming a mean shear modulus make such reductions of test results by simplified formula arbitrary and unreliable.

More general expressions are formed for spars of circular and square section, introducing three elastic coefficients, numerical values of which are computed and tabulated from measurements of torsion tests by Stamer and Sieglerschmidt on specimens of oak, red beech and oregon pine.

If rhombic symmetry of the material is assumed there are nine elastic coefficients. These are computed and tabulated from the same tests, and figures for spruce computed from Carrington's tests are added for comparison.

Nine references.

Mercerisation of Cotton for Strength, with Special Reference to Aircraft Cloth. (J. B. Wilkie, N.A.C.A. Tech. Note No. 450, 1933.) (10.424/28104 U.S.A.)

Mercerisation treatment with caustic solution increases the strength of the yarn from 40 to 100 per cent., comparing equal weights. During treatment the temperature should be kept below 0°C. and sufficient tensions maintained to prevent a shrinkage of over 3 per cent.

Two references.

Testing Apparatus and Methods of Testing

Supersonic Wind Channel for Model Tests. (W. Margoulis, Comptes Rendus, No. 196, 1933, p. 24; Phys. Berichte, No. 23, 1/12/33, p. 1916.) (11.10/28105 France.)

A blower delivers an air jet of 8 cm. diameter at velocities up to 925 m. per sec. Model test results differed fundamentally from those at ordinary velocities and the physical explanation will require new developments of hydrodynamical theory.

The Farnborough Seaplane Tank. (L. P. Coombes and W. G. A. Perring, Airc. Eng., Vol. 6, No. 61, March, 1934, pp. 63-66.) (11.20/28106 Great Britain.)

A note is given on the historical development of tank research. A table shows comparative data of German, American and Farnborough tanks. Considered reasons are given for the comparatively small dimensions of the latter. A description is given of the equipment and mounting of models.

A programme of tests covers the technical problems under consideration.

[An article by S. Truscott on the N.A.C.A. high speed tank follows. (See Abstract No. 28114.)]

Tank Tests of Two Floats for High-Speed Seaplanes. (J. W. Bell, N.A.C.A. Tech. Note No. 473, 1933.) (11.22/28107 U.S.A.)

Two quarter-scale seaplane float models were tested at speeds up to 60ft. per sec., one similar to the floats of the 1926 Macchi Schneider Trophy competitor, the other a new design.

The test figures show the improved water performance of the latter. It is also expected that the air resistance will be lower on test.

One reference.

Scale Effect in Model Tests in Marine and Aircraft Construction. (F. Gutsche, Z.V.D.I., Vol. 77, No. 47, 25/11/33, pp. 1255-1260.) (11.22/28108 Germany.)

Scale effects are largely dependent on surface friction, which in its turn determines instability of the boundary layer. Polished and roughened models show considerable difference in the high speed wind channel. In the case of propellers, the problem is complicated by hull interference and cavitation.

Twelve references.

Complete Tank Test of Model of a Flying Boat Hull, N.A.C.A. Model No. 11. (J. M. Shoemaker and J. B. Parkinson, N.A.C.A. Tech. Note No. 464.) (11.22/28109 U.S.A.)

Authors' abstract.—This note discusses the limitations of the conventional tank test of a seaplane model. The advantages of a complete test, giving the characteristics of the model at all speeds, loads, and trim angles in the useful range, are pointed out.

The data on N.A.C.A. Model No. 11, obtained from a complete test, are presented and discussed. The results are analysed to determine the best trim angle for each speed and load. The data for the best angles are reduced to non-dimensional form for ease of comparison and application.

A practical problem using the characteristics of Model No. 11 is presented to show the method of calculating the take-off time and run of a seaplane from these data.

Six references.

Complete Tank Test of Model of a Flying Boat Hull, N.A.C.A. Model No. 11*A.* (J. B. Parkinson, N.A.C.A. Tech. Note No. 470, 1933.) (11.22/28110 U.S.A.)

From author's abstract.—Model No. 11A was designed as an improvement on Model No. 11, a complete test of which is described in Tech. Note No. 464. In contrast with the longitudinal upward curvature in the planing bottom forward of the main step on Model No. 11, the planing bottom of Model No. 11A was made as flat as practicable. Otherwise, the two models have nearly the same form.

Towing test data are given in tables and curves for a wide range of speed, load on the water, and trim angle, along with non-dimensional coefficients. The improvement obtained is demonstrated by applying the data from Model 11A to the illustrative design problem in the note on Model No. 11.

Two references.

Complete Tank Test of Model of a Flying Boat Hull, N.A.C.A. Model No. 16. (J. M. Shoemaker, N.A.C.A. Tech. Note No. 471.) (11.22/28111 U.S.A.)

From author's abstract.—A model of a two-step flying boat hull, of the type generally used in England, was tested according to the complete method described in N.A.C.A. Tech. Note No. 464. The lines of this model were taken from offsets given by Mr. William Munro in *Flight*, May 29th, 1931. The data

cover the range of loads, speeds and trim angles required for design. The results are reduced to non-dimensional form for design problems and for comparison with hulls.

The water characteristics of Model No. 16 are compared with those of Model 11A, which is representative of current American practice. Under optimum conditions for each, the performance of Model No. 16 will be somewhat inferior to that of Model No. 11A.

Five references.

Effect of Spray Strips on a Model of the P3M-1 Flying Boat Hull. (J. R. Dawson, N.A.C.A. Tech. Note No. 482, 1933.) (11.22/28112 U.S.A.)

From author's abstract.—A series of tests was made in the N.A.C.A. tank on a sixth scale model of the hull and side floats of the Navy P3M-1 flying boat for the purpose of reducing the amount of spray thrown into the propellers when taking off and landing.

The model was tested bare and with five spray-strip arrangements. The best arrangement was an improvement over the bare hull, but not sufficient to be satisfactory with the propellers in the designed position.

One reference.

Hydrodynamic Knowledge and Measures for the Improvement of Ship Propulsion. (E. Klindwort, Z.V.D.I., Vol. 77, No. 47, 25/11/33, pp. 1267-1269.) (11.22/28113 Germany.)

Improvements are due to changes in the shape of the hull, as well as propeller and rudder position. By altering the nose part only of certain liners of the Hamburg-America Line a reduction of 10 per cent. in the drag has been achieved. The interaction of propeller, hull and rudder is more complicated and the reason for the undoubted improvements which have been achieved in certain cases by relatively small modifications are not always understood.

Photographs of the development of cavitation round a propeller are given.

Six references.

High Speed Towing Basin for Model Floats. (S. Truscott, N.A.C.A. Report No. 470, 1933, 23 pages.) (11.22/28114 U.S.A.)

General arrangement sketches give the plan side and end elevations of the basin, building and towing plant. Photographs show a general view of Langley Field buildings, the empty basin and the towing apparatus. The free towing length is about 1,080ft. (600 metres), width 24ft. (7.3 metres), depth 12ft. (3.65 metres); maximum towing carriage speed 88ft. per sec. (27 metres per sec.).

Froude's conditions of dynamical similitude are given for dimensions, speeds, forces and moments.

Tests on different types of step fitted to the same flying boat hull at three or four different incidences are given graphically. Fluting the steps fore and aft has no substantial effect on performance. In every case there is a discontinuous drop in resistance at the critical speed of change from buoyancy to hydroplaning.

Eight references.

Balloons

Selection of Favourable Winds by Control of Altitude. (P. Perlewitz, Z.F.M., Vol. 24, No. 21, 4/11/33, pp. 586-589.) (12.19/28115 Germany.)

The horizontal travel of free balloons is entirely dependent on the wind prevailing at selected altitudes, but airships and aeroplanes can profitably study the variation of wind with altitude and apply the knowledge to increasing their effective performance.

A description is given, with a sketch and two photographs, of a micro-compass with a fixed reflecting prism bringing the compass card into the field of view and a rotatable prism for bringing a fixed object into the field of view. Particulars for four free balloon voyages are illustrated by maps showing changes in direction of course.

Seven references.

Wireless

Natural Frequency of Electromagnetic Oscillations in Conductors of Straight, Circular and Spiral Form. (K. F. Lindman, Ann. d. Phys., Vol. 18, No. 7, Dec., 1933, pp. 805-815.) (13.2/28116 Germany.)

The experimental layout is described and numerical values are shown graphically in comparison with previous results, which require considerable modification.

Nine references.

Ferrocart, a Magnetic Material for High Frequencies. (A. Schneider, Z.V.D.I., Vol. 77, No. 46, 18/11/33, pp. 1233-1235.) (13.2/28117 Germany.)

Thin strips of paper coated with Ni/Fe particles varying from 5 to 20 μ diameter in an adhesive insulating emulsion are built up into laminated plates 2-3 mm. thick. The plates, cut to shape, form the core of high frequency coils which give sharp tuning in wireless circuits, since they are practically free from hysteresis.

Two references.

Wave Forms at a Distance from a Dipole Sender with Different Conductivities and Di-Electric Coefficients at the Earth's Surface. (K. F. Niessen, Ann. d. Phys., Vol. 18, No. 8, Dec., 1933, pp. 893-912.) (13.30/28118 Germany.)

A mathematical physical discussion is given of the general problem of the form of waves emitted from a dipole sender at a height above the earth which is considerable compared with the dimensions of the sender. Wave forms are calculated for four different wave lengths and for four different assumptions as to the dielectric coefficient and conductivity at the earth's surface, corresponding to dry land, moist land, fresh water and salt water. The angular relations are shown graphically.

Reception from Synchronised Broadcast Stations. (C. B. Aiken, Bell Tele., No. B-758.) (13.32/28119 U.S.A.)

Phase differences between carrier waves and side frequencies are the principal causes of distortion, and time delays of the order of 200 micro-seconds have serious effects at receivers outside the region between the stations. At points between the stations at less than 40 km. distance there is no distortion between identical modulated waves. This suggests the application of a number of lower power recorders distributed round the area and supplied by transmission circuits with identical modulated waves from a central station. The total radiated power required would be far less than for a single station and the total sky wave and interference outside the area would also be reduced.

Thirteen references.

Vacuum Tubes of Small Dimensions. (B. J. Thompson and G. M. Rose, Proc. Inst. Rad. Eng., Vol. 21, No. 12, Dec., 1933, pp. 1707-1721.) (13.5/28120 U.S.A.)

Photographs show two small tubes in different aspects. The linear dimensions are of the order of 1/10th the conventional size and the interelectrode capacities are correspondingly reduced.

Successful applications have been made to receiving on wave lengths from 100 cm. down to 30 cm.

Aircraft Radio Direction Finder. (W. S. Hinman, Jr., Bur. Stan. J. Res., Vol. 11, No. 6, Dec., 1933, pp. 733-741.) (13.6/28121 U.S.A.)

A directional dissymmetrical loop antenna is reversed with respect to the ground, thereby producing two equal and opposite distorted field curves. The reversal is accomplished by alternately grounding the ends through rectifier tubes, and applying the voltage induced in the loop to a radio receiver. The dissymmetry of the circuit involves the matching of a pair of resistances within ½ per cent. A pair of condensers is also matched.

A diagram of connections is given and photographs show the aerial mounted in an aeroplane, the circuit installation and the course indicator dial.

An angular calibration curve is obtained by swinging the aeroplane and shows a maximum deviation of 2°. Some operational experiences are given and a claim is made to freedom from serious course errors unless the loop antenna is resonated below the bearing station frequency.

New Field of Application for Ultra-Short Waves. (E. Kramar, Proc. Inst. Rad. Eng., Vol. 21, No. 11, Nov., 1933, pp. 1519-1531.) (13.6/28122 U.S.A.)

From author's abstract.—A new method of forming a guide ray by keying the reflectors is stated. The dependence of the guide ray upon size, spacing and number of reflectors is measured. There is no distortion due to reflections. A description is given of the use of the radio range beacon for blind landing of airplanes in thick weather. Simultaneous visual and aural reception in the airplane is possible without changing the method of keying the transmitter.

Nine references.

Short Wave Propagation in the Atmosphere. (K. Försterling and H. Lassen, H.F. Technik., Vol. 42, No. 5, Nov., 1933, pp. 158-178.) (13.6/28123 Germany.)

The authors examine the propagation of electro-magnetic waves in an ionised gas subjected to a magnetic field. The well known dependence of range and intensity of wireless signal on time of day and wave length is correlated with the presence of two conducting layers in the upper atmosphere. The so-called double echo is explained by magnetic double refraction.

Eleven references and 25 illustrations.

Progress in Photo-Electric Cells with a "Resistor" Dielectric Layer. (F. Rother and H. Bomke, Phys. Zeit., Vol. 34, No. 23, 1/12/33, pp. 805-870.) (13.7/28124 Germany.)

The formation of a layer of copper sub-oxide between the metal surface of a sheet of copper and a layer of higher copper oxides is the basis of a new technique in photo-electric cells. More complicated arrangements are also discussed. Methods of preparation are described and the observed relation between the current (of ions) and the light intensity is shown graphically. A substantial advance in photo-electric sensitiveness is claimed.

Ten references.

Experimental Television. (E. W. Engstrom, Proc. Inst. Rad. Eng., Vol. 21, No. 12, Dec., 1933, pp. 1652-1654.) (13.7/28125 U.S.A.)

Application of the cathode ray tube as the image producing element of the receiver depends on control of direction and intensity of the ray. The beam is controlled by two variable magnetic fields, vertical and horizontal, with frequencies of 24 and 2,880 cycles per second.

Diagrams of connection and calibration curves of the elements are given. Synchronisation is maintained by periodic synchronising impulses.

Two references.

Electron Conductivity of Copper Sub-Oxide. (W. Schottky and F. Waibe, Phys. Zeit., Vol. 34, No. 23, 1/12/33, pp. 858-864.) (13.7/28127 Germany.)

Experimental results on the displacement of electrons in a layer of copper sub-oxide are given in tables and are plotted graphically. A theoretical discussion takes into account the wave properties of an electron to explain anomalies arising from the corpuscular conception. The method has important applications. (See Abstract 28124.)

Eleven references.

Modes of Vibration of Piezo Electric Crystals. (H. Straubel, Phys. Zeit., Vol. 34, No. 24, 15/12/33, pp. 894-896.) (13.81/28128 Germany.)

The modes are made visible by optical interference patterns, in reflected rays. With ordinary light the interference pattern does not show the nodal lines. By placing the quartz crystal parallel to the second mirror of a Micheion interferometer adjusted to give uniform darkness initially, under vibration the nodal lines remain dark, while the vibrating portions become bright.

Nine photographs of patterns are reproduced.

Four references.

Photography

Memoranda on Air Photography. (H. Roussilhe, Pub. Sc. et Tech., No. 30, 1933.) (14.00/28129 France.)

A permanent advisory committee has been formed to consult with the French Air Ministry on optics and aerial photography. The present number contains six reports on standardisation, interchangeability and multiple lens photography.

A report on the stereotopographic instrument of Poivilliers will be presented shortly.

Thirty-nine illustrations.

Photogrammetric Apparatus. (O. v. Gruber, Z.V.D.I., Vol. 77, No. 44, 4/11/33, pp. 1177-1180.) (14.40/28130 Germany.)

A brief description of recent apparatus is illustrated by fourteen photographs.

A circular cylinder carrying a film is adapted for panoramic views from a single point. A specimen film is reproduced with sliding scales for reading off direction and elevation of details. Aerial cameras include double and quadruple cameras with focal lines at fixed angles for taking two or four oblique photographs simultaneously.

A pocket stereoscope is suitable for rapid inspection and a table stereoscope with a micrometer for adjusting the two views is capable of more exact work. A bench stereoplanigraph of the most elaborate type is also shown.

Two references.

Air Navigation and Maps

International Air Maps. (R. Grasso, Riv. Aeron., No. 11, Nov., 1933, pp. 205-233.) (15.5/28131 Italy.)

The international standardisation of air maps is discussed in relation to the decision taken at the various international congresses. A list of agreed symbols is given.

A brief account is given of the characteristics of national surveys and air maps.

Accidents and Precautions

Regulations for Rescue Service on Seaplane Lines. (A. Pirozzi, Riv. Aeron., No. 11, Nov., 1933, pp. 275-283.) (16.15/28132 Italy.)

A clear map shows the network of Italian seaplane routes in central and eastern Mediterranean. A summary is given of the principal decisions of the Italian air authorities for rescue and salvage preparation and operation.

Examples of Damage to Aircraft by Lightning. (H. Koppe, Z.F.M., Vol. 24, No. 21, 4/11/33, pp. 577-580.) (16.30/28133 Germany.)

The electrical fields round pylons, trees, buildings, free and moored balloons, dirigibles and aircraft with and without trailing antennæ are shown graphically in a diagram. The generation of an electrical field in the atmosphere by precipitation is discussed.

A list of recorded accidents from direct lightning stroke is given, a total of 31, only one of which is previous to 1925. An analysis of the accidents by constructional details is given. In 26 cases out of 29 in which lightning struck directly, antennæ were being towed. Photographs of damaged parts are reproduced.

One reference.

Aircraft—Unorthodox

Simplified Aerodynamic Analysis of the Cyclogiro Rotating Wing System. (J. B. Wheatley, N.A.C.A. Tech. Note No. 467, 1933.) (17.05/28134 U.S.A.)

From author's abstract.—A simplified aerodynamic theory is presented, with numerical examples showing the effect of varying the design parameters. A performance prediction indicates the feasibility of hovering flight, vertical climb, and reasonable forward speed under normal expenditure of power and gliding descent with autorotation under no power.

Wing Pressure Distribution and Blade Motion of Autogiro in Flight. (J. B. Wheatley, N.A.C.A. Report No. 475, 1933, 11 pages.) (17.05/28135 U.S.A.)

The type under test had wings of 30.3ft. span and 101 sq. ft. projected area. The incidence of wing to rotor disc was 3.6°. Pressure orifices were distributed over the wings and the contribution of one wing was determined in steady flight and of both wings in accelerated flight and in turns.

A cinema camera was mounted on the rotor hub, pointing along a blade, and the angular position was determined from the record. Reduced plots of the blade angle for a complete cycle are shown for speeds of 30 m.p.h. and 105 m.p.h. The numerous recorded points lie very closely on mean periodic curves and show the change in phase and amplitude very clearly. At 30 m.p.h. the blade moved between 4.6° and 10.2° about a mean of 7.4°, the amplitude being 2.8° with a phase advance of about 35°. At 105 m.p.h. the blade moved between −0.6° and +13° about a mean of 6.2°, the amplitude being 6.5° with a phase advance of 65°. The rolling axis is taken as zero azimuth.

Lift coefficients of wing and rotor, rotor speeds, coning and flapping angles and proportion of load carried by wing are plotted as functions of tip speed to air speed ratio. Distributions of lift are plotted under various conditions.

The data are of importance in checking the semi-empirical formulæ in use.

Aerodynamic Tests of a Low Aspect Ratio Tapered Wing with an Auxiliary Aerofoil for Use on Tailless Aeroplanes. (R. Sanders, N.A.C.A. Tech. Note No. 477, 1933.) (17.30/28136 U.S.A.)

From author's abstract.—In wind tunnel tests of a model wing with aspect ratio 3, tapered plan form, straight trailing edge and a fixed auxiliary aerofoil

of constant chord, trimming moments were obtained by the upward deflection of a full span, constant chord trailing edge flap.

The auxiliary aerofoil increased the maximum lift of the model in about the same proportion as the drag for high speed flight. The lift in the trimmed condition compares favourably with that of a conventional aeroplane.

The improvements by application of the auxiliary aerofoil in the position tested, *i.e.*, parallel to the leading edge, did not justify the complication.

Eleven references.

Aerodynamic Tests of a Low Aspect Ratio Tapered Wing for Use on Tailless Aeroplanes. (F. E. Weick and R. Sanders, N.A.C.A. Tech. Note No. 463, 1933.) (17.30/28137 U.S.A.)

From authors' abstract.—Wind tunnel tests were made of a model wing having an aspect ratio of 3, a tapered plan form with a straight trailing edge, a Clark Y aerofoil section and no washout, longitudinal balance and control, depending on a trailing edge flap. The wing has aerodynamic characteristics well suited for use on tailless aeroplanes.

Eight references.

Meteorology and Physiology

Change of State of Moist Air. (F. Bosnjakovic, F.G.I., Vol. 4, No. 6, Nov./Dec., 1933, pp. 280-286.) (19.10/28138 Germany.)

The entropy-water content diagram of moist air is constructed for use in conjunction with the total heat-water content diagram of Mollier, with applications to the equilibrium of atmospheric air and the compression of fuel mixtures.

Eight references.

Branching of Lightning and Polarity of Thunderclouds. (J. C. Jensen, J. Frank. Inst., Vol. 216, No. 6, Dec., 1933, pp. 707-748.) (19.10/28139 U.S.A.)

A summary is given of various explanations of electrification of clouds, most weight being given to Simpson's " divided rain drop " theory. The effects of ionisation on the stratosphere in increasing or decreasing the charge are discussed. Ionisation in the lower levels of the atmosphere is taken as the chief cause of branching of lightning for positive discharges only. Diagrams of cloud formation illustrate the argument. Numerous photographs of lightning are reproduced.

Thirty references.

Extraterrestrial Electrical Disturbance. (K. G. Jansky, Bell Tele., No. B-764, 1933.) (19.10/28140 U.S.A.)

Space-directional observations of certain high frequency atmospherics observed throughout the day and year show a diurnal and annual period. The mean right ascension is $270° \pm 7\frac{1}{2}°$ and a declination of $-10° \pm 30°$. The wide scattering in declination is attributed to the ionised layers of the earth's atmosphere and to attenuation over the earth's surface.

Six references.

Functioning of the Nasal Organs in High Altitude Flying. (A. Mangiacapra, Riv. Aeron., No. 11, Nov., 1933, pp. 258-274.) (19.20/28141 Italy.)

The symptoms affecting the nasal organs are classified. In a number of test flights, some up to 7,000 m., schedules of progress in symptoms are given for every 1,000 m. in ascent and descent. Recommendations for treatment are given.

Physiological and Psychological Effects of Fatigue on the Activity of the Pilot. (G. Fatuzzo, Riv. Aeron., No. 11, Nov., 1933, pp. 284-291.) (19.29/28142 Italy.)

The results of investigations on industrial fatigue are discussed briefly with reference to the selection of pilots.

Effect of Acceleration on the Human Frame. (H. v. Diringshofen, Z.F.M., Vol. 24, No. 21, 4/11/33, pp. 589-592.) (19.29/28143 Germany.)

The physical factors and the physiological effects are discussed along the usual lines. The advantages of a semi-recumbent position are brought out.

Five recommendations are made—the selection of small pilots, abdominal pressure belts and special development of the abdominal muscles, semi-recumbent or recumbent position, special dieting immediately before flight, use of drugs.

Compressor for Oxygen and Acetylene. Method of Storing. (V. Fischer, Z.V.D.I., Vol. 77, No. 45, 11/11/33, pp. 1212-1214.) (19.32/28144 Germany.)

Oxygen compressors are lubricated with water, since the ordinary lubricants decompose explosively. The piston is sealed with flexible fibre bushes and the stuffing box is made of leather. Parallel piston motion without side thrust is obtained by flexible mounting of the piston rod on the cross head.

In the case of acetylene, normal piston rings and oil lubrication can be employed, but extra cooling is required as acetylene is liable to decompose explosively. Acetylene is so highly soluble in acetone that the saturated solution stored in cylinders at 15 atmospheres yields a volume of free gas comparable with that given by oxygen cylinders of equal volume at 150 atmospheres.

Two references.

Lighting—Visibility

Transmissibility of Visible Light Through a Cloud of Particles. (D. Nukiyama, Aeronautical Research Institute, Tokyo, Report No. 98, Vol. 8, No. 2, Dec., 1933.) (21.22/28145 Japan.)

Beams of light were transmitted through clouds of incense smoke of NH_4Cl particles. The intensity decrement was measured and the results were plotted against the inverse fourth power of the wave length. An approximately linear relation was obtained for small wave lengths, but irregularities appear for larger wave lengths, and the separation of absorption and scattering effects is not attempted. Direct photographic measurement of scattered light intensity was undertaken.

The general arrangement of the optical apparatus with cloud producing apparatus (NH_4Cl) is shown in a diagrammatic sketch. The cloud was formed in a circular cylindrical vessel. A specimen photographic film is reproduced, along with graphical records prepared from it.

Finally, the results are given in numerical tables and in diagrams of intensity of scattered light in radial directions from the axis of the cylinder. Comparison is made with physical theory, but the discrepancies suggest that the scattering particles used are of more complicated type than those assumed by Rayleigh, Mie, Blumer and others.

Ten references.

Aerodynamics and Hydrodynamics

Determination of the Velocity Potential. (F. Vasilesco, Pub. Sc. et Tech., No. 29, 1933.) (22.10/28146 France.)

A method proposed by Riabouchinsky for expressing the velocity potential in terms of initial boundary surface conditions is developed at some length, particularly for a spherical boundary in terms of spherical harmonics, with discussion of existence theorems and conditions of convergency.

Three references.

Temperature and Velocity Field Round a Heated Pipe in the Case of Free Convection. (K. Jodlbauer, F.G.I., Vol. 4, No. 4, July/Aug., 1933, pp. 157-172.) (22.10/28147 Germany.)

The experiments were carried out on pipes of 20, 50 and 90 mm. diameter at various surface temperatures up to 150°C., with air temperature, at a distance, 20°C. throughout. The temperature distribution in the heated air was measured with a fine wire thermocouple (.015 mm.); the air speeds were recorded by deflection of a quartz fibre viewed by microscope. There is evidence that the instrument disturbed the experimental conditions.

An attempt is made to develop a formula for the heat transfer of large tubes which seems to give results of the right order for Grashof numbers above 10^4.

Nine references.

Theory of Viscosity of Liquids. (E. N. da C. Andrade, Phil. Mag., Vol. 17, No. 112, Feb., 1934, pp. 497-511, and No. 113, pp. 698-732.) (22.10/28148 Great Britain.)

Molecular spacing of fluids is much nearer that of the solid than of the gaseous state and the frequency of molecular vibration in the liquid state just above melting point may be taken as equal to the frequency in the solid state just below melting point.

Considering a sheet of molecular thickness, between two adjacent parallel molecular sheets in relative shearing motion a molecule in the middle sheet in the course of a vibration may enter combination with the nearest molecules in an adjacent sheet during the extreme stage of vibration and thus transfer momentum, but in the mean range may pass from the molecular field of the nearest molecule to the field of an adjacent molecule in the direction of shear displacement. This simple conception, together with established relations of molecular physics, leads to an expression for viscosity containing one arbitrary coefficient and yielding remarkable agreements.

The relative orientation of molecules affects the molecular exchanges and the viscosity. If the solid state is assumed to give the orientation of maximum molecular field, then rise of temperature will cause the orientation to approach random distribution and the mutual molecular fields will be weakened and the viscosity will decrease.

When these further considerations are taken into account the previous expression may be generalised, but two experimental coefficients are now introduced. When these coefficients have been determined for one temperature the viscosity is immediately expressed for a range of temperatures above melting point. Ninety organic substances show agreement substantially within the experimental error.

Chlorine, iodine and mercury also show close agreement, but water shows a discrepancy of -15 per cent. to $+27$ per cent. and two organic substances show discrepancies of the same order as water. Mercury gives good agreement.

One of the coefficients is about 1/10th of the total internal energy in the solid state derived from Waal's equation of state for a large number of substances, but anomalous cases arise.

The wide range of agreements indicates that important correlations have been established. The essential mechanism of viscosity is the same as for gases and depends on collisions and exchanges of momentum, but the molecular paths are very different in magnitude and direction and the exchanges of momentum differ in frequency, duration and intensity.

Fifty-two references.

Measure of Viscosity by the Uniform Motion of a Sphere in a Circular Cylinder. (G. Duffing, Z.A.M.M., Vol. 13, No. 5, Oct., 1933, pp. 366-373.) (22.10/28149 Germany.)

Simplifying assumptions lead to an approximate expression for the resistance of a sphere moving with small clearances in a long cylinder, which is applied to the design of a viscosimeter.

A satisfactory fit is obtained with the results of direct calibration.

Four references.

Flow Experiments in a Rotating Laboratory. (G. Vogelpohl, Z.V.D.I., Vol. 77, No. 48, 2/12/33, p. 1294.) (22.10/28150 Germany.)

Experiments have been carried out at Göttingen on the velocity distribution of straight and curved rotating channels, both instruments and observer sharing the rotation. The relative motion calculated for a frictionless fluid is a useful first approximation of observed motion.

Two references.

Turbulent Flow between Two Rotating Co-Axial Cylinders. (F. Wendt, Ing. Arch., Vol. 4, No. 6, Dec., 1933, pp. 577-595.) (22.15/28151 Germany.)

A description is given of an elaborate apparatus for repeating G. I. Taylor's classical experiment. The outer cylinder has a fixed radius of 14.70 cm. and three inner cylinders could be fitted with radii of 10.00 cm., 12.50 cm. and 13.75 cm.

There are fittings for measuring pressure distribution, mean fluid velocity and torque. The r.p.m. varied from $+172$ to -172 and the velocity field was explored by a pitot tube inserted between the cylinders and carried through a mercury seal to the manometer.

The end effect was shown by fitting a flat end disc alternatively at rest or rotating. It is large for the greatest difference of radii, 4.75 cm., but almost insensible for the smallest difference, 0.95 cm. The readings were extended with the turbulent range far beyond the critical speeds and the resistance coefficients derived from the measurements show characteristics of the same general nature as for flow in a pipe. The critical speeds agree fairly closely with Taylor's results.

Eleven references.

Diffusion of Vorticity in Laminar Motion. (W. Müller, Z.A.M.M., Vol. 13, No. 6, Dec., 1933, pp. 395-408.) (22.15/28152 Germany.)

The author discusses the diffusion of vorticity into an infinite viscous fluid.

1. From a plane laminar jet initially in uniform motion between the plane boundaries.
2. From a uniform initial distribution of vorticity in a circular cylindrical sheet.
3. From a circular cylindrical jet initially in uniform axial motion.

Formal solutions are obtained in terms of the error function for the plane boundaries and of Bessel functions for the cylindrical boundaries.

Numerical results are given graphically.

Twelve references.

Small Disturbances of an Infinite Set of Eddies. (G. Durand, Pub. Sc. et Tech., No. 35, 1933.) (22.15/28153 France.)

The motion of a long but finite single row of equal and equally spaced vortices is considered, first near the centre of symmetry, then near a vortex which divides the row into unequal sets (p and $p+m$).

The velocity potential now contains the additional term $\log m/p$, which the author considers paradoxical. [A physical interpretation is easily given by considering the initial field of a finite rectilinear vortex sheet, near the centre of symmetry and near a point dividing it in the ratio of $p:(p+m)$; all, of course, before the rolling up of the ends has proceeded to any appreciable extent.] The case of two rows is then considered, for symmetrical and staggered formation, and v. Kàrmàn's result is obtained for the latter.

From the form of the solution it is inferred that an initial disturbance which alters the mean relative position of the two rows from v. Kàrmàn's equilibrium configuration produces an unstable condition, in other words, that disturbances which have not zero mean value over a finite length, tend to increase with time.

Measurement of Water Flow with Venturi Channels. (F. Engel, Z.V.D.I., Vol. 77, No. 48, 2/12/33, pp. 1285-1287.) (22.2/28154 Germany.)

The open Venturi channel is less affected than a weir by muddy water and the loss of head is less as there is a considerable recovery of energy.

The author has calibrated a Venturi channel over a considerable range of flows in terms of two non-dimension parameters, the Reynolds and the Boussinesque numbers. The flow is affected by waves in the throat of the channel and further investigation with channels of this type may throw light on wave formation and ship propulsion.

Nine references.

Contributions to the Knowledge of the Flow Resistance of Curved Rough Pipes. (O. Fritzsche and H. Richter, F.G.I., Vol. 4, No. 6, Nov./Dec., 1933, pp. 307-314.) (22.2/28155 Germany.)

The resistance in an indiarubber tube 10 m. long and approximately 20 mm. internal diameter laid out straight was approximately the same as that of a commercial brass tube.

The roughness of the internal surface was therefore taken to be of the same order and may be designated as "commercially smooth." The rubber tube was bent in successive curves and the resistance measured for Reynolds number from 3,000 to 300,000 both with air and water. Tables give the pressure drops due to friction and to curvature (the values of the latter being obtained presumably by subtraction of the total resistances in the two cases).

Twelve references.

Approximation to Entry Flow in a Pipe. (G. Vogelpohl, Z.A.M.M., Vol. 13, No. 6, Dec., 1933, pp. 446-447.) (22.2/28156 Germany.)

The author forms the equation of accelerated motion from initial uniform flow in a long pipe with constant axial pressure gradient and obtains the subsequent distribution of velocity as a function of time and radius until the steady parabolic distribution of velocity is set up.

The total flow is variable in time, with initial and final flow equal. In order to maintain uniform flow throughout the whole time of transition a variable axial pressure gradient is required and is determined by an integral equation, the solution of which is known.

The numerical values of the first three coefficients in the comparison are given. Lanchester's transformation for the entry flow from a reservoir is suggested and further corrections are indicated.

Two references.

Conditions of Flow in a Vertical Bend. (C. Keutner, Z.V.D.I., Vol. 77, No. 45, 11/11/33, pp. 1205-1209.) (22.2/28157 Germany.)

The bend had a diameter of 25 cm. The rate of flow was varied from 0.3 to 4 m. per sec. The pressure distribution along the wall and the velocity distribution across a number of sections were determined.

On account of the unsteady nature of the flow simultaneous photographic registering of the readings was employed. In the centrifugal field of force the retarded boundary layers flow inward and the unretarded fluid outwards, along the radius of the bend, just as in a horizontal bend.

(The practical value of the investigation is small, as guide vanes at sharp bends give much superior results.)

Nineteen references.

Characteristics of Sprays from Pintle-Type Injection Nozzles. (E. T. Marsh and C. D. Waldron, N.A.C.A. Tech. Note No. 465, 1933.) (22.2/28158 U.S.A.)

From authors' abstract.—Tests were made with two injection nozzles, one having a pintle angle of 8°, the other of 30°. The fuel was injected into a glass-windowed pressure chamber and the spray photographed. Curves give the penetration of the spray tips of fuel oil injected by pressures of 1,500 to 4,000 pounds per square inch into air at room temperature and densities of 11 to 18 atmospheres.

The pintle angles have little effect on the size of the spray cone angle, which is about the same as that of sprays from plain round-hole orifices. The penetration with an 8° pintle is slightly higher than with a 30° pintle. Increase in air density decreases the penetration in about the same ratio for all the injection pressures.

Fourteen references.

Formation of Stationary Surface Waves. (W. Schuler, Z.A.M.M., Vol. 13, No. 6, Dec., 1933, pp. 443-446.) (22.35/28159 Germany.)

When a long circular cylinder or a wedge is immersed symmetrically and subjected to forced oscillation progressive waves are formed which travel at right angles to the line of immersion and, under certain conditions, stationary waves are formed along the line of immersion.

When a sphere is submerged a semi-diameter and subjected to oscillation, progressive waves are formed which travel radially outward and standing waves are formed round the circle of immersion. The critical condition depends on the amplitude as well as the frequency of the forced oscillation. No physical explanation is offered.

Photographs of Fluid Flow by Ultramicroscope. (A. Fage, Proc. Roy. Soc., Vol. 144, No. A.852, 29/3/34, pp. 381-386.) (22.36/28160 Great Britain.)

A description is given of an established method of illuminating microscopic particles, such as are carried in ordinary tap water, by an intense beam of light which renders the particles visible against a dark background.

The present paper describes the further progress of the technique from visual observation to the photographic record. Nineteen such photographs are reproduced and show the paths of suspended particles in unobstructed channels and in the neighbourhood of cylinders and triangular prisms.

Six references.

Experiments on Fluid Motion in the Marseilles Institute of Fluid Mechanics. (P. Léglise, L'Aéron., No. 173, Oct., 1933, p. 227.) (22.36/22.76/28161 France.)

A summary is given of work by J. Valensi. Two strobometric photographs with exposures of 1/50 and $1/10^6$ secs. show flow past a wing in a wind jet 0.67 m. × 0.65 m. with a velocity of 39 m. per sec.

A strobometric photograph shows flow past a cylinder of 10 mm. dia. in a jet of water velocity 2.10 m. per sec. exposure $1/10^6$ sec.

Resistance of Air to Oscillatory Motions. (M. le Rolland, L'Aéron., No. 173, Oct., 1933, pp. 231-232.) (22.76/28162 France.)

Serious complications are introduced by the variable motion. The results are expressed in empirical expressions. The hot wire measurement, calibration and compensation are of interest. A smoke indicator shows the formation of eddies at the edge of an oscillating plate.

Experiments on Fluid Motion in the Toulouse Institute of Fluid Mechanics. (C. Camichel and others, L'Aéron., No. 173, Oct., 1933, p. 228.) (22.76/28163 France.)

Photographs show a steady vortex pair behind a plate, vortices formed by the rolling up of layers of transition, turbulent flow at a boundary and laminar flow in the body of the fluid, and steady laminar flow near a plate. The first is a good example of strobometric methods of determining the velocity field.

Materials—Elasticity and Plasticity

Strain Stress and Small Oscillations of Beams with Initial Curvature and Twist, in Rotation with a Transverse Axis. (H. Reissner, Ing. Arch., Vol. 4, No. 6, Dec., 1933, pp. 557-569.) (23.30/28164 Germany.)

The problem of strain and stress in the blades of a rotating turbine or screw is more general than similar problems dealt with by various authors and included in Love's text book. In the present paper the differential equations are further developed to include the effects of large screw pitch and of high angular velocities.

The elastic and dynamical equations are formed along usual lines, and permissible approximates are discussed. Numerical values of the coefficients are derived from tests of materials (metals and timbers) and the results are put in a suitable form for computations.

Numerical applications will follow in a subsequent report.

Four references.

Stresses Induced by Flexure in a Deep Rectangular Beam. (D. B. Smith and R. V. Southwell, Proc. Roy. Soc., Vol. 143, No. A.849, 1/1/34, pp. 271-284.) (23.30/28165 Great Britain.)

St. Venant's solution is an approximation to a more general result. A second approximation is expressed formally and values obtained by numerical solution are exhibited graphically. A third approximation is unnecessary for practical design, but shows the interesting fact that the neutral axis is sensibly nearer the compression side.

Five references.

New Method of Calculating the Buckling Load in Struts of Variable Section. (K. Hohenemser, Z.F.M., Vol. 24, No. 22, 28/11/33, pp. 609-614, and No. 23, 14/12/33, pp. 640-644.) (23.30/28166 Germany.)

The conditions for buckling are expressed as an integral equation and a formal solution is expressed as a series. An approximate solution is obtained by various simplifying assumptions.

Numerical values of the parameters are computed and tabulated and applied to particular cases in comparison with the values given by approximate formulæ. The method is applied to buckling with a number of nodes. A numerical example is fully worked out.

Eight references.

Stability of Thin-Walled Tubes Under Torsion. (L. H. Donnell, N.A.C.A. Report No. 479, 1933, 24 pages.) (23.30/28167 U.S.A.)

Numerous test data are collected and shown graphically in comparison with different types of approximate solutions. A description is given of the test apparatus, illustrated by sketches and by photographs showing the mounting of specimens and examples of failure under load.

A critical historical note shows the relation of the paper to previous work, in particular to the methods and solution of Southwell and Skan for a flat strip, which is a limiting case of the present problem. The elastic equations are expressed in cylindrical co-ordinates and, after simplifying approximations have been introduced, the solution is formed in terms of algebraic parameters and Fourier series, including the elastic coefficients and the dimensions of the tube.

Numerical values are computed, tabulated and shown graphically.

Eleven references.

Thin-Walled Duralumin Cylinders in Compression. (E. E. Lundquist, N.A.C.A. Report No. 473, 1933, 20 pages.) (23.30/28168 U.S.A.)

In continuation of Report No. 427, further test results are collected. Photographs show specimens mounted in the test apparatus and examples of symmetrical and asymmetrical buckling.

Previous approximate solutions of the equations of elastic instability are discussed and compared with each other and with experiment. The experimental points are rather widely scattered about a mean test curve.

A critical length is defined in terms of which a distinction is drawn between " long " and " short " cylinders, and rules are given for bulkhead spacing.

Twenty-six references.

Strength Tests of Thin-Walled Duralumin Cylinders in Pure Bending. (E. E. Lundquist, N.A.C.A. Tech. Note No. 479, 1933.) (23.30/28169 U.S.A.)

From author's abstract.—This report, the third of a series, presents the results of strength tests on thin-walled cylinders and truncated cones of circular and elliptic section, including pure bending tests on 58 thin-walled duralumin cylinders of circular section with ends clamped to rigid bulkheads. The stress on the extreme fibre at failure, calculated by the ordinary theory of bending, is from 30 to 80 per cent. greater than the compressive stress at failure for thin-walled cylinders in compression. The length/radius ratio has no consistent effect upon the bending strength. In cylinders of the same dimensions the size of the wrinkles on the compression half in bending is approximately equal to the size round the complete circumference in compression.

Six references.

Exact Solutions of Notch Effect in Discs and Cylinders. (H. Neuber, Z.A.M.M., Vol. 13, No. 6, Dec., 1933, pp. 439-442.) (23.30/28170 Germany.)

The elastic equations are written down with solutions for a variety of boundaries. The fields of stress are shown graphically.

Five references.

Torsional Stresses in Thin-Walled Box Girders, with Constraint against Curvature of Cross Section Members. (H. Ebner, Z.F.M., Vol. 24, No. 23, 14/12/33, pp. 645-655, and No. 24, 28/12/33, pp. 684-692. D.V.L. Report, No. 349.) (23.41/28171 Germany.)

Reference is made to formulæ given by R. Bredt (1896) for computation of stresses in box girders with free curvature in cross sections. The present paper develops the corresponding formulæ when such curvature is completely prevented by constraints.

In aeroplane practice such constraints are partially imposed, *e.g.*, by stiffener, and the method is extended to calculation of the corresponding departure from the values given by Bredt's formulæ.

Numerical examples are worked out. The analysis, which follows the usual lines, is heavy and unsuitable for abstracting.

Fifteen references.

Summary of Design Formulæ for Beams having Thin Webs in Diagonal Tension. (P. Kuhn, N.A.C.A. Tech. Note No. 469.) (23.41/28172 U.S.A.)

Author's abstract.—This report presents an explanation of the fundamental principles and a summary of the essential formulæ for the design of diagonal-tension field beams, *i.e.*, beams with very thin webs, as developed by Professor Wagner, of Germany.

Seven references.

Comparison of Three Methods for Calculating Compressive Strength of Flat and Slightly Curved Sheet and Stiffener Combinations. (E. E. Lundquist, N.A.C.A. Tech. Note No. 455, 1933.) (23.41/28173 U.S.A.)

From author's abstract.—A comparison is made of three methods for calculating the compressive strength of flat sheet and stiffener combinations in stressed-skin or monocoque structures for aircraft. The method based upon joint action of the stiffener and an effective width of sheet as a column, gave the best agreement with tests.

Seven references.

Pendulum Tests of Structural Rigidity. (M. le Rolland, L'Aéron., No. 173, Oct., 1933, p. 230.) (23.46/28174 France.)

A simple illustrative example is given in the form of a vertical encastré beam with a short cross piece at the upper end carrying two equal pendulums. The first pendulum is set in motion and transfers its energy to the second pendulum. The elementary relation is given between the rigidity of the test piece and the time of transfer.

A more elaborate application to a framed structure enables similar structures, manufactured in series, to be compared.

Miscellaneous

Uniformity of Symbols in Aircraft Structural Calculations. (A. Teichmann, Z.F.M., Vol. 24, No. 23, 14/12/33, pp. 655-660.) (28175 Germany.)

To facilitate interchange and comparison of results a systematic scheme of lettering diagrams and denoting mechanical quantities is proposed under the auspices of the German Standard Committee for Aeronautics. Double, triple and quadruple suffixes are employed to meet the exigencies of denoting the mass of geometrical and mechanical terms involved.

Three references.

REVIEWS

Air Adventure

By William Seabrook. Published by George G. Harrop and Co., Ltd. Price 8s. 6d.

This is a story of a flight from Paris to Timbuctu and back in a single-engined Farman aeroplane. The Sahara is crossed twice by the Trans-Saharan route and the various adventures of the expedition are well told by an author who understands the use of words, and who recognises a picturesque incident with the skill born of experience.

The party consisted of an American lady novelist, a French officer-pilot and the author. The description given of the Trans-Saharan route is of considerable interest as this route is little known except to certain French pilots. At Reggan, somewhere about the middle of the Sahara, there is a well appointed hotel where it was possible to obtain whiskies and sodas at the bar; and the party sat down to a French table-d'hôte dinner and found bedrooms fitted with electric light and decorated with art curtains. Even the famous Bidou S., the place supposed to be unapproachable except by aeroplane and motor transport, possessed certain creature comforts, and it was found possible to pass a comfortable night in what are described as dismantled bus shelters.

Some delay is caused by a dust storm which necessitates a forced landing, the survival of the party being probably due to the desert experience of the pilot, and Timbuctu is reached without further trouble. On the return journey the programme is interfered with owing to a French aeroplane having been lost, and the lady member of the expedition has an adventure of her own while travelling by land transport. We learn that certain of the oases in this district are supplied with water by an underground system of conduits, of unknown date, and there is a remarkable ruined castle with a mysterious altar.

The chief interest of the book is the details given of the French organisation of the Saharan air route. There is no doubt that the utmost credit is due to those who organised this route and to those who fly over it. The difficulties are serious, dust storms are not infrequent, and the wheel marks in the sand are often obliterated, making it more difficult for aircraft and ground transport to find their way. But the route seems to be a perfectly practical one to those who possess experience of its conditions and the delays which are now inevitable will doubtless grow less as this experience increases.

This book is one which should be read. Mr. Seabrook possesses a pleasant style, and has produced a narrative which reads easily and which contains information of value.

The First War in the Air

By R. H. Kiernan. Published by Peter Davies, Ltd. Price 5/-.

At last we have a good condensed history of the War in the air. The author has avoided the mistakes made by most of the other historians and the result of reading his book enables one to obtain a general view of the principal events in perspective. He never loses sight of the fact that a wood cannot be adequately

described by appending a detailed list of the peculiar attributes of each individual tree.

He has also interwoven into the story sufficient details of the general course of events on the ground and at sea to enable the reader to form an opinion of the interaction between the Air Force and the other Services, to understand how the strategy of the one must sometimes be dependent on the requirements of the other, and to trace the effect of the development of aircraft design on the operations. This matter had a special influence on air fighting, owing to the comparative rapidity with which improved types of aircraft could be produced; consequently the advantage of possessing the best types oscillated between the combatants, but belonged to us during the later stages.

The gallantry with which the air war was fought and the chivalry often shown between combatants is one of the more remarkable features of the fighting, and the author appropriately uses as a chapter heading a quotation from William Napier: "Why are young men told to look in ancient history for examples of heroism, when their own countrymen furnish such lessons?"

At its price of 5s. the book is excellent value and it can be thoroughly recommended to those who want to know what happened without wading through masses of detail.

The Air Annual of the British Empire, 1934-35

Published by Sir Isaac Pitman and Sons, Ltd. Price 15/-.

The latest volume of this well-known annual is of the same high standard as its predecessors. There are a number of excellent articles on various Service matters of general interest, and Mr. E. Colston Shepherd writes with knowledge on Commercial Flying Progress within the Empire. Mr. H. J. Thomas contributes an interesting summary of the recent progress of the British Aircraft Industry. There are also articles on technical subjects by Mr. M. Langley and Mr. Handley Page, and also by Mr. W. H. Dyson, etc.

Many will find the greatest value of the book to lie in the detailed descriptions and specifications of British aircraft and aero engines, and the chapter devoted to components. These are very well done and contain much information which cannot be found in any similar book. But why is the Popjoy not on the list of aero engines approved as being airworthy?

This work is not only useful for reference, but it contains many articles which are well worth reading. It should be on the shelves of every aeronautical library.

On the Wing

By David Masters. Published by Eyre and Spottiswoode. Price 8s. 6d.

Mr. Masters has written this book with the wholly admirable idea of giving the general public some insight into the more spectacular aeroplane achievements, and the contents list shows that he has selected his subjects well. He starts, very properly, with the Wright Brothers, continues with Santos Dumont, A. V. Roe and Cody, and goes on to war subjects, Schneider Trophy Races, and such matters as record flights, etc.

The first requirement of a book of this type is that it should be accurate in its facts. Unfortunately it contains a number of serious errors from which I select specimens for correction. The Phillips wing form was not used by Lilienthal as stated, neither was a Demoiselle aeroplane used by Santos Dumont when he made the first flight in Europe. The year was 1906, not 1907. Roe triplanes were not used in the Great War, and Voisin was not the designer of

the Antoinette monoplane. The early Farman biplane is incorrectly stated to resemble the Wright Brothers' machine; almost the only resemblance was that they both were biplanes. The Vickers biplane used by Alcock and Whitten Brown for the first Atlantic crossing was not, as stated, a single-engine machine; it had two engines. The Schneider Trophy is not silver-gilt, but plain silver. Carbon dioxide is not a deadly poison; the author is probably thinking of carbon monoxide, a very different substance.

Sometimes the narrative descends to sensationalism and becomes ridiculous. We read of a pilot whose eyeballs froze solid, thereby causing a violent explosion in his head; and of speeds so high that the air friction scoured the dope from the wings.

The two best chapters in the book are those on heroes of the Royal Air Force, and on Captain Morris's adventure in the North Sea, which are written with a restraint which adds immensely to the force of the description. Had the author used a similar style everywhere and avoided inaccuracy the book would have been a welcome addition to aeronautical literature.

RESEARCHES INTO THE THEORY OF THE TOWNEND RING

BY

CAPTAIN DR. G. OTTEN *

Foreword

The Townend Ring has been the subject of a large amount of experimental research and its general characteristics are now well understood. The following paper is the first theoretical treatment of the ring which has appeared. It was originally presented as a thesis to the University of Delft by Capt. G. Otten and published in Holland in November, 1932. The author has made the following abbreviated translation of it into English in collaboration with Dr. H. C. H. Townend, who also suggested a few modifications.

CHAPTER I.

(a) Résumé of Townend's Experiments: Classification in Two Groups

Townend's experiments,† relating to the interference between an engine model or an airship model and a surrounding ring, may be classified in two groups. In the first group a ring of symmetrical section is placed round the nose of an airship model with the centre line of the section parallel to the direction of the local airflow (Fig. 1). All the other experiments must be placed in the second group.

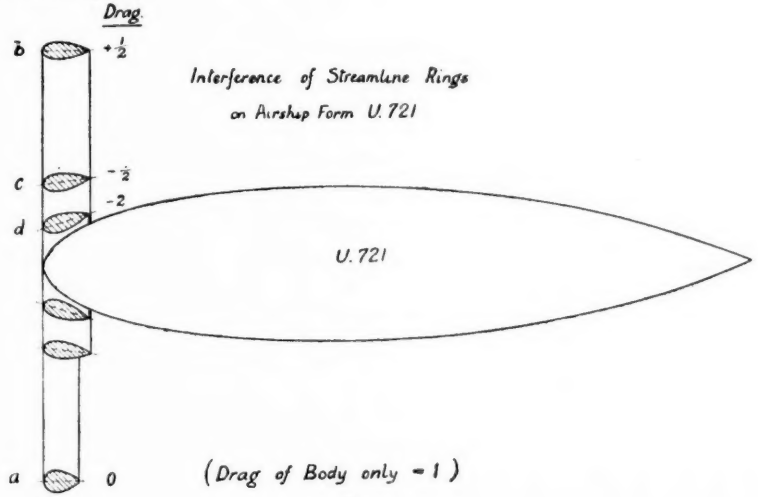

FIG. 1.

* Engineer Officer, Royal Dutch Air Force, East Indies.

† Published in R. & M. 1267, and also in "Aircraft Engineering," April, 1930, and the Journal of the Royal Aeronautical Society, October, 1930.

The difference between the effects of the ring in the two cases may be summarised as follows:—

In the first group the drag of the ring was large compared with that of the body alone, whilst the influence of the ring when near the body was such as to reduce the drag of the body still further. Moreover, with rings having less than a certain diameter, the drag became negative for suitable arrangements. The only plausible explanation would seem to be that a reduction in pressure over the nose occurred resulting, according to Bernoulli's equation, from a local acceleration in the speed between the ring and body above its normal value. The ring and body would thereby be drawn towards one another, as in the well known case of a ball suspended from a suitably shaped air jet.

The experiments in group two show exactly the opposite effect. Here, the overall resistance was reduced; and in the cases in which it was measured the drag of the body (which now includes a radial engine) was increased while the drag of the ring generally became negative. The best results were obtained by giving the ring an aerofoil section, working preferably at a high lift coefficient. When an aerofoil works at a high lift coefficient, however, the pressure below it is higher than that above it, or in the case of the ring the pressure inside is increased and that outside is reduced. It then follows from Bernoulli's equation that the velocity between ring and body is reduced so that the condition of flow is of quite a different nature than in the tests of the first group. The position of the model in the second group can be compared with that of the Handley Page slot.

Hence there was but a slight connection between Townend's initial tests, which led to the discovery of the ring, and those concerned with its application to the radial engine, as Townend was himself well aware.

(b) The Action of the Townend Ring and of the Aerofoil

What caused the reduction in drag in Townend's second group of tests? For a given diameter of ring Townend found that the reduction depended chiefly upon the lift coefficient, angle of incidence and chord of the ring section. These are the same factors which determine the lift of an aerofoil, whilst a change in them affects the reduction in drag in the same sense as it affects the lift of an aerofoil. Hence, there must be a close relation between the properties of an aerofoil and the action of the Townend Ring.

As in the case of the aerofoil there must clearly be a circulation round the section of the ring, so directed that the velocity inside the ring is reduced, and therefore the drag of any object inside it. The latter is in apparent contradiction with the results of Townend's experiments. Again, the ring is situated in a region where the velocity is modified by the presence of the body and engine which deflect the air outwards. In consequence the resultant force on an element of the ring is not quite radial, but has a forward component which tends to push the ring towards the nose. This effect was emphasised by Townend. He also pointed out the reduction of velocity inside the ring caused by the circulation, but does not appear to have given it much attention except for its influence on the cooling of the engine.

After a discussion with Prof. J. M. Burgers, Chief of the Laboratorium voor de Hydro- en Aerodynamica at Delft, and Mr. C. Koning, Engineer at the Rijks-Studiedienst voor de Luchtvaart, at Amsterdam, it seemed likely that a research on the effect of the reduction in velocity on the drag might yield interesting results, particularly when an object of simple form was chosen.

In order to keep the experimental part of the work as simple as possible, attention was at first confined to a two-dimensional case, namely, the interference of two straight aerofoils on a gauze screen placed between them. We will now consider this case theoretically.

CHAPTER II.

THEORETICAL TREATMENT OF THE DRAG OF A GAUZE SCREEN PLACED BETWEEN TWO AEROFOILS

(a) The Flow through a Gauze Screen: First Approximation

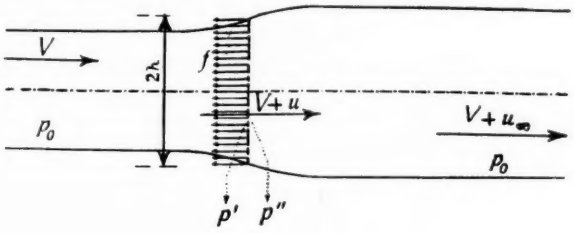

FIG. 2.

Let us first consider the flow through a gauze screen when no aerofoils are present.

Let V be the velocity of the undisturbed stream; $V+u$ the actual velocity through the gauze; $V+u_\infty$ the velocity at a great distance behind the gauze; p_0 the pressure a great distance in front of the gauze; p' and p'' the pressures just in front of and just behind the gauze. These changes of velocity and pressure are caused by the drag of the gauze. Let f be the drag of the gauze per unit area, and $2h$ the breadth of the gauze.

The following equations can now be derived with the help of the momentum theorem, Bernoulli's equation and the laws of equilibrium:—

$$2hf = -2h\rho\,(V+u)\,u_\infty \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$p_0 + \tfrac{1}{2}\rho V^2 = p' + \tfrac{1}{2}\rho\,(V+u)^2 \quad . \quad . \quad . \quad . \quad (2)$$

$$p'' + \tfrac{1}{2}\rho\,(V+u)^2 = p_0 + \tfrac{1}{2}\rho\,(V+u_\infty)^2 \quad . \quad . \quad . \quad . \quad (3)$$

$$p'' - p' = f \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

From (2), (3) and (4) we get

$$\rho\,(V+\tfrac{1}{2}u_\infty)\,u_\infty = -f \quad . \quad . \quad . \quad . \quad . \quad (5)$$

and from (1)

$$\rho\,(V+u)\,u_\infty = -f \quad . \quad . \quad . \quad . \quad . \quad (6)$$

so that

$$u = \tfrac{1}{2}u_\infty \text{ or } u_\infty = 2u \quad . \quad . \quad . \quad . \quad . \quad (7)$$

Equation (7) shows that, as in airscrew theory, half the change in velocity occurs in front of the gauze.

Now we can also write

$$f = \tfrac{1}{2}k\rho\,(V+u)^2 \quad . \quad . \quad . \quad . \quad . \quad (8)$$

where k is the drag coefficient of the gauze referred to the velocity at the gauze.

In the following we will assume that the disturbance due to the gauze is small. Then u and u_∞ will be small compared with V, while (6) shows that f will be small compared with ρV^2, so that from (8) k will be a small number. In expanding $(V+u)^2$ we will therefore neglect powers of u higher than the first; thus we get

$$f \approx \tfrac{1}{2}k\rho\,(V^2 + 2Vu)$$

For u the first approximation will suffice here, hence, from (5) and (7)

$$u=\tfrac{1}{2}u_\infty \cong -f/2\rho\,(V+u) \cong -f/2\rho V.$$

Thus

$$f \cong \tfrac{1}{2}k\rho\,(V^2-f/\rho)$$

so that

$$f \cong \{\,k/(k/2+1)\,\}\,(\rho V^2/2) \qquad (9)$$

Hence the factor $k/(1+\frac{1}{2}k)$ is the drag coefficient of the gauze referred to the velocity of the free stream. This we will denote by k_1, so that

$$f=k_1\,(\rho V^2/2) \qquad (9a)$$

Let us now consider the case in which there are two stationary vortices of opposite sign in the field of flow, located symmetrically in the plane of the gauze, each at a distance a from its centre. The circulation Γ due to the vortices is taken as positive when its induced velocity at the gauze is in the opposite direction to the free stream. The arrangement is shown diagrammatically in Fig. 3.

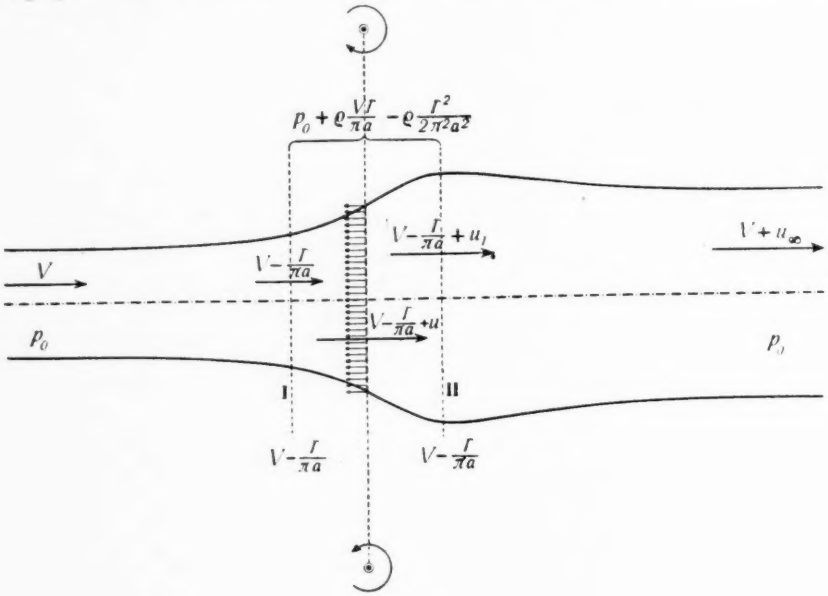

FIG. 3.

In this figure is also shown the boundary of the stream which passes through the gauze and thus experiences its direct interference.

Near the gauze the velocity is reduced by the amount $u'=\Gamma/\pi a$ on account of the vortices, a quantity which we will regard as small compared with V. If we also take a large compared with $2h$, then u' may be considered constant over the gauze. At the same time the pressure in this region is increased to

$$p_0+\tfrac{1}{2}\rho V^2-\tfrac{1}{2}\rho\,(V-u')^2=p_0+\rho\Gamma V/\pi a-\rho\Gamma^2/2\pi^2a^2.$$

Far in front of and behind the gauze u' falls to zero while the pressure regains the initial value p_0.

If we now consider two sections I and II so chosen that they lie within the region of increased pressure, we may apply equations (1) to (4) provided we

write $V-u'$ (or $V-\Gamma/\pi a$) for V, and $p_0+\rho\Gamma V/\pi a-\rho\Gamma^2/2\pi^2a^2$ for p_0. We may also put u_1 for u_∞. We then obtain, by analogy with (5) and (6)

$$\rho\,(V-u'+\tfrac{1}{2}u_1)\,u_1=\rho\,(V-\Gamma/\pi a+\tfrac{1}{2}u_1)\,u_1=-f \quad . \quad . \quad (5a)$$

$$\rho\,(V-u'+u)\,u_1=\rho\,(V-\Gamma/\pi a+u)\,u_1=-f \quad . \quad . \quad (6a)$$

so that in this case also

$$u_1=2u \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7a)$$

For the drag per unit breadth of the gauze we must now write

$$f=\tfrac{1}{2}k\rho\,(V-u'+u)^2 \quad . \quad . \quad . \quad . \quad . \quad (8a)$$

which may be reduced as before to

$$f=-\tfrac{1}{2}k_1\rho\,(V-u')^2=\tfrac{1}{2}k_1\rho\,(V-\Gamma/\pi a)^2 \quad . \quad . \quad . \quad (9b)$$

or to the same degree of approximation as before

$$f=\tfrac{1}{2}k_1\rho V^2\,(1-2\Gamma/\pi aV),$$

which can be written as

$$f=f_0\,(1-2\Gamma/\pi aV) \quad . \quad . \quad . \quad . \quad (10)$$

where f_0 is the drag per unit area of gauze in the absence of the vortices.

To find the velocity $V+u_\infty$ attained by the air so far downstream that the interference of the vortices has practically disappeared, we apply Bernoulli's equation to the flow beyond section II, which gives

$$p_0+\rho V\Gamma/\pi a-\rho\Gamma^2/2\pi^2a^2+\tfrac{1}{2}\rho\,(V-\Gamma/\pi a+u_1)^2=p_0+\tfrac{1}{2}\rho\,(V+u_\infty)^2$$

leading to

$$(V-\Gamma/\pi a+u_1/2)\,u_1=(V+u_\infty/2)\,u$$

which gives approximately

$$u_\infty=u_1\,(1-\Gamma/\pi aV) \quad . \quad . \quad . \quad . \quad . \quad (11)$$

Since u_1 and u_∞ are negative and Γ positive, the retardation decreases, *i.e.*, the speed increases again whilst the breadth of the " wake " contracts as shown in Fig. 3 beyond section II.

Lastly the loss of momentum experienced by the flow is

$$-2h\rho\,(V-\Gamma/\pi a+u)\,u_\infty$$

which, from (5*a*) and (11) may be written

$$2hf\,(1-\Gamma/\pi aV)$$

or by applying (10)

$$2hf_0\,(1-3\Gamma/\pi aV) \quad . \quad . \quad . \quad . \quad . \quad (12)$$

Thus the momentum loss with vortices present is less than when they are absent in the ratio $(1-3\Gamma/\pi aV)$.

Why is the reduction in the drag of the gauze less than the above change in momentum? Consider the influence of the gauze on the vortices.

As already seen, the velocity change behind the gauze due to the force f is, to the first order

$$u_1\cong -f/\rho V.$$

This may be considered as the effect of an additional flow

$$Q\cong -2hu_1\cong 2hf/\rho V$$

due to a source Q at infinity.

At the vortices this source gives a velocity*

$$v=Q/2\pi a=hf/\pi\rho Va \quad . \quad . \quad . \quad . \quad (13)$$

* In later calculations (p. **897**) a more accurate expression for v is desirable, but as the inclusion of terms of the second order presents great difficulties we have written from (6a)

$$Q=-2hu_1=2hf/\rho(V-u'+u)$$

from which v is deduced in the usual manner. This method may not be quite satisfactory, as only part of the second order terms are used, but for small values of a, however, they seem to be the more important ones.

at right angles to the stream. Hence, by Joukowski's formula, there will be a force

$$K = hf\Gamma/\pi aV \quad . \quad . \quad . \quad . \quad . \quad (14)$$

acting in an *upstream* direction, *i.e.*, a towing force.

The towing force on both vortices is $2hf\Gamma/\pi aV$, or, per unit area of gauze, $f\Gamma/\pi aV$.

The nett resistance per unit surface of gauze, of the gauze and vortices combined is then

$$f^* = f(1 - \Gamma/\pi aV)$$

or, from (10)

$$f^* = f_0(1 - 3\Gamma/\pi aV) \quad . \quad . \quad . \quad . \quad (15)$$

This expression agrees with (12) and shows that the overall drag is less than that of the gauze alone in the ratio $(1 - 3\Gamma/\pi aV)$, which is the amount by which the momentum loss is reduced.

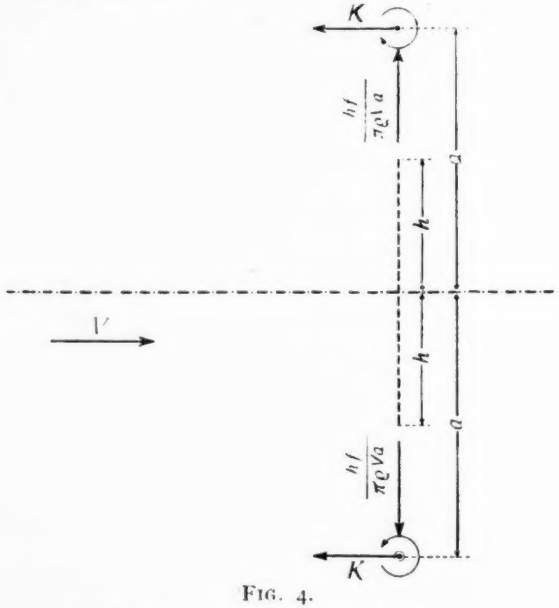

FIG. 4.

It may be shown that the ratio of the drag reduction of the gauze to the towing force on the vortices depends upon the exponent of the velocity in the formula for the drag of the gauze.

Calling the drag per unit area of the gauze, without vortices,

$$f_0 = \tfrac{1}{2}k\rho V^n$$

we find

$$f = \tfrac{1}{2}k(V - \Gamma/\pi a)^n \text{ or}$$

$$f \cong f_0(1 - n\Gamma/\pi aV)$$

so that the drag reduction is equal to $f_0 \cdot n\Gamma/\pi aV$.

The towing force on the two vortices per unit area of gauze is

$$f\Gamma/\pi aV$$

hence

$$\text{drag reduction/towing force} = n(f_0/f) \cong n.$$

For the case of two aerofoils, and also for the case of the Townend Ring, this is proved in a similar manner.

The following conclusions may be drawn from (10) and (15):—

CONCLUSION I.—When a gauze screen is situated between two vortices, in the manner considered above, it undergoes a reduction of drag which varies directly as its free-air drag and the strength of the vortices, and inversely as velocity of the stream and the distance between the vortices.

CONCLUSION II.—The vortices will experience forces, urging them against the stream, whose sum is approximately half the reduction in drag experienced by the gauze.

Thus the overall reduction in drag of the whole system is approximately 50 per cent. greater than the reduction in drag of the gauze alone.

(b) Vortices replaced by Aerofoils

In Fig. 5 each vortex has been replaced by an aerofoil. Since Γ represents the strength of the circulation, the formula

$$L=\rho V\Gamma$$

applies in either case, but while in the case of the vortex the core is concentrated

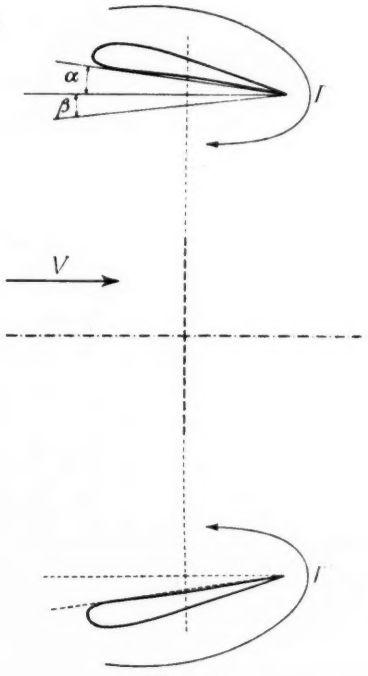

FIG. 5.

at the axis, in the case of the aerofoil it consists of the whole section. As explained later, however, beyond a certain distance the aerofoil behaves approximately as a vortex. With this assumption Conclusion I holds for aerofoils also provided their mutual interference is neglected. Hence, if a is large compared

with the breadth of the gauze, the resistance of the gauze when situated between aerofoils is also

$$f=f_0(1-2\Gamma/\pi aV \quad . \quad . \quad . \quad . \quad . \quad (11)$$

per unit area. Putting $\Gamma=k_L Vc$ we get

$$f=f_0(1-2k_L c/\pi a) \quad . \quad . \quad . \quad . \quad . \quad (16)$$

k_L is now a function, not of α only, but of $(\alpha+\beta)$ where β is the inclination of the local flow to that of the general stream.

The interference velocity due to the gauze will be the same as with the vortex, namely,

$$v \cong hf/\pi\rho Va \quad . \quad . \quad . \quad . \quad . \quad (13)$$

so that

$$\tan\beta=v/V=hf/\pi\rho aV^2$$

Approximating for f we get

$$\tan\beta \cong k_1 h/2\pi a \quad . \quad . \quad . \quad . \quad . \quad (17)$$

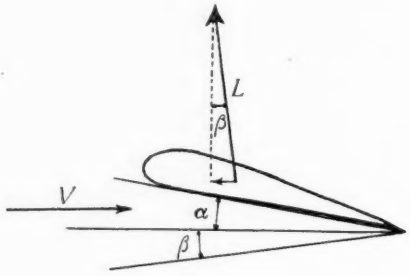

FIG. 6.

As the lift of the aerofoil is perpendicular to the direction of the local streamlines, which is inclined to that of the main stream by the angle β it will have a component $L\sin\beta$, or $k_L\rho V^2 c\sin\beta$, acting upstream. This component is of course merely the force K in (14).

The drag of the aerofoil, acting along the direction of the streamlines is

$$k_{D0}\rho V^2 c^*$$

This drag has a downstream component

$$k_{D0}\rho V^2 c\cos\beta$$

The resultant axial force is

$$T=(k_L\sin\beta-k_{D0}\cos\beta)\rho V^2 c \quad . \quad . \quad . \quad . \quad (18)$$

which is positive when

$$k_L\tan\beta-k_{D0}>0$$

i.e., when

$$k_L(k_1 h/2\pi a)-k_{D0}>0$$

If $m=k_L/k_{D0}$, the lift-drag ratio for infinite aspect ratio, the condition becomes

$$2\pi a/h<mk_1 \quad . \quad . \quad . \quad . \quad . \quad (19)$$

(c) The Velocity Field below a Single Aerofoil

Hitherto the breadth of the gauze was considered relatively small compared with its mean distance from the aerofoil. Calculation then showed that the reduction in drag was inversely proportional to this distance. Hence the aerofoil

* As the motion is two-dimensional, the induced drag is zero, so that the frictional drag coefficient alone appears.

should be placed as near the edge of the gauze as possible. But this raises the question as to whether the substitution of a vortex for an aerofoil is permissible. It is therefore necessary to compare the velocity fields due to the aerofoil and to the vortex.

With an aerofoil of arbitrary section it is difficult to express the velocity field mathematically; a knowledge of k_L as a function of α is not sufficient.

The field may be ascertained experimentally, especially if the distribution is only required along one line. Alternatively, the following approximate method may be used.

The pressure distribution round the aerofoil is first measured and the aerofoil is then replaced by its centre-line curve. At a finite number of points on this curve vortices are placed, the strength of each being calculated from Joukowski's equation and the measured value of the lift per unit length at the corresponding point, and the spacing of the vortices. The velocity at every point in the field due to all the vortices may then be found, though obviously the method is very laborious.

A comparison by this means, between the fields due to a Joukowski aerofoil and a vortex has been made, as the velocity field could be completely calculated by conformal transformation. As a simple case a circular arc aerofoil was chosen. The following conclusions were reached:—

Conclusion III.—For a given circulation a reduction in speed occurs which diminishes as the distance from the section increases.

Conclusion IV.—In calculating the velocity below the centre of the section, a vortex may be substituted for the section to find the velocity at points which are more than one chord length from the section, whilst for nearer points approximation to the velocity may be obtained with the aid of a parabola.

The above mentioned parabola may be calculated as follows:—Measuring abscissæ parallel to the stream and ordinates normal to it, with the origin in the section; then calling the area under the section positive, if u_{po} be the velocity reduction for $y=0$, and u'_o the reduction for $0 \leqq y \leqq c$, the following points must lie on the parabola:—

$$y=0,\ u'_o=u_{po},$$
$$y=c,\ u'_o=\Gamma_o/2\pi c,$$

while the direction of the tangent to the parabola at $y=c$ must be the same as for the curve $u'_o=\Gamma_o/2\pi y$. As can be seen the parabola

$$u'_o=(u_{po}/c^2-\Gamma_o/\pi c^3)\,y^2-(2u_{po}/c-3\Gamma_o/2\pi c^2)\,y+u_{po} \quad . \quad . \quad (20)$$

fulfils these conditions.

(d) The Velocity Field between Two Aerofoils

Having found the field below a single aerofoil, it is necessary to find the mutual interference between two aerofoils before the field between them can be found, since obviously each will modify the flow around the other.

Let A and B (Fig. 7) be two similar sections arranged symmetrically a distance of $2a$ apart in a uniform stream of velocity V.

We will assume $a > c$, so that A behaves, at B, as if it were a vortex and conversely.

Let Γ be the circulation round each aerofoil and V_A the velocity near A, if A were removed, but its influence on B retained. Let V_B be similarly defined. Then

$$V_A=V_B=V-\Gamma/4\pi a \quad . \quad . \quad . \quad . \quad . \quad (21)$$

Let Γ_o be the circulation that would exist if one aerofoil were removed altogether. Then

$$\Gamma_o=k_L V_o \quad . \quad . \quad . \quad . \quad . \quad (22)$$

From (21) it follows that

$$\Gamma = k_L (V - \Gamma/4\pi a) c,$$

so that

$$\Gamma = (\Gamma_0/V)(V - \Gamma/4\pi a)$$
$$= \Gamma_0 \{ 1 - \Gamma_0/(4\pi a V + \Gamma_0) \} \quad . \quad . \quad . \quad . \quad (23)$$

which shows that the change in circulation due to the mutual interference of the aerofoils is

$$-\Gamma_0^2/(4\pi a V + \Gamma_0).$$

Equation (23) may be written

$$\Gamma = \Gamma_0 \{ 1 - k_L c/(4\pi a + k_L c) \} \quad . \quad . \quad . \quad (23a)$$

from which, knowing k_L and c, Γ may be found immediately.

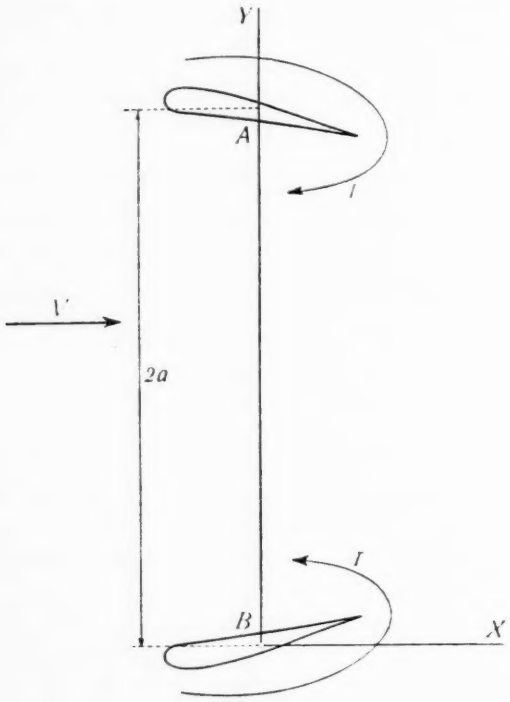

FIG. 7.

From (21) we have

$$V_A = V_B = V \{ 1 - k_L c/(4\pi a + k_L c) \} \quad . \quad . \quad . \quad (24)$$

which shows that, due to mutual interference, the aerofoils behave as if the wind velocity were reduced in the ratio $k_L c/(4\pi a + k_L c)$.

We may now say that the velocity field between two aerofoils may be calculated for points more than one chord distant from both aerofoils by replacing the aerofoils by vortices, while for points nearer to one aerofoil, the velocity may be approximated by a parabola and the other aerofoil being replaced by a vortex.

Taking axes as shown in Fig. 7 we obtain, for the interval $c \leqq y \leqq 2a-c$,

$$V_x = V - \Gamma/2\pi\,(2a-y) - \Gamma/2\pi y = V - a\Gamma/\pi y\,(2a-y) \quad . \quad . \quad (25)$$

If the origin is taken midway between the aerofoils to that $y = y_1 + a$, (25) becomes

$$V_x = V - a\Gamma/\pi\,(a^2 - y^2{}_1).$$

This shows that the reduction in velocity, over the region considered, is smallest midway between the aerofoils and increases towards them.

From (23*a*) we may write

$$V_x = V - \{\, a\Gamma_0/\pi\,(a^2 - y^2{}_1)\,\} \cdot \{\, 1 - k_L c/(4\pi a + k_L c)\,\}$$

and, as $\Gamma_0 = k_L c V$ we have

$$V_x = V\,\{\, 1 - 4a^2 k_L c/(a^2 - y^2{}_1)\,(4\pi a + k_L c)\,\} \quad . \quad . \quad (26a)$$

From this it follows that the reduction in velocity is directly proportional to the velocity of the stream. If a is large compared with c (26*a*) becomes approximately

$$V_x \cong V\,\{\, 1 - a k_L c/\pi\,(a^2 - y_1{}^2)\,\} = V - a\Gamma_0/\pi\,(a^2 - y_1{}^2) \quad . \quad (26b)$$

which, in conjunction with (26), means that the mutual interference between the aerofoils may be neglected.

The error introduced by using (26*b*) instead of (26*a*) is greatest when $k_L c$ is a maximum, *i.e.*, when $k_L = k_{L\max}$ and $c = a$. Taking $k_{L\max} = \pi/5 = 0.63$, the maximum error will be about 5 per cent. From (26*b*) it follows that for $c \leqq y \leqq 2a - c$ the velocity reduction is, to a close approximation, proportional to the circulation.

Writing (26*b*) as

$$V_x = V - \Gamma_0/\pi\,(a - y^2{}_1/a)$$

we see that the velocity reduction in the space between the aerofoils increases rapidly as the aerofoils approach one another.

Let us now consider the field close to one of the aerofoils, say, the interval $0 \leqq y \leqq c$.

From (20) the velocities in this region can be found as follows:—

$$V_x = V - (u_p/c^2 - \Gamma/\pi c^3)\,y^2 + (2u_p/c - 3\Gamma/2\pi c^2)\,y - u_p - \Gamma/2\pi\,(2a-y)$$

in which u_p is found by multiplying u_{po} by the factor $V_B/V = 1 - k_L c/(4\pi a + k_L c)$, so that

$$V_x = V - \{\, (u_{po}/c^2 - \Gamma_0/\pi c^3)\,y^3 - (2u_{po}/c - 3\Gamma_0/2\pi c^2)\,y + u_{po} + \Gamma_0/2\pi\,(2a-y)\,\} \cdot \{\, 1 - k_L c/(4\pi a + k_L c)\,\} \quad . \quad . \quad (27)$$

which may also be written as follows:—

$$V_x = V - \{\, u'_0 + \Gamma_0/2\pi\,(2a-y)\,\} \cdot \{\, 1 - k_L c/(4\pi a + k_L c)\,\} \quad . \quad (27a)$$

For the circular arc section it can be shown, and for all other normal wing sections safely assumed, that, for the whole interval $0 < y < c$, the velocity reduction decreases if the aerofoils are placed farther apart. We may say, therefore, that the effect of increasing the distance between the aerofoils is similar—although less—in the interval $0 < y < c$ as in the interval $c < y < 2a - c$, *i.e.*, it causes a decrease in the velocity reduction.

In (27*a*) u'_0 is the velocity reduction at a distance $y = c$ below a single aerofoil with circulation Γ_0. u'_0 increases as y decreases. $\Gamma_0/2\pi\,(2a-y)$ may be considered as the velocity reduction below the same section at a distance $2a - y$. This latter reduction decreases as y decreases. From the properties of the single aerofoil it follows, however, that when y decreases, the decrease in the velocity reduction at distance $2a - y$ is less than the increase in u'_0. Hence the factor $u'_0 + \Gamma_0/2\pi\,(2a-y)$ increases as y decreases so that the velocity reduction increases as the aerofoil is approached.

For two aerofoils we may therefore say that, in the whole area between them, the velocity is highest midway between them and decreases on moving outwards.

Finally it may be concluded from the formulæ that, neglecting the correction represented by the factor $\{1-k_L c/(4\pi a+k_L c)\}$, the velocity reduction is, at all points between the aerofoils, proportional to the circulation round the section.

In order to assess the accuracy with which equations (23), etc., represent the mutual interference, appeal was again made to the circular arc sections and by a conformal transformation the change in the circulation was determined. An exact calculation of the velocity field is not possible by this means as only one section can be transformed into a circle. One section therefore was replaced by a vortex having a strength equal to the circulation round the section. The error introduced in this way will be quite small if the formula for the velocity is applied only to that part of the field in which the section is situated.

The differences between the velocities found in this way and those calculated from (25) and (27) for a distance of 1 metre between two sections having a chord of 0.24 metre working at lift coefficient of $k_L=\pi/12$ and $\pi/3$ amount to 1.2 per cent. and 2.1 per cent. respectively with an average less than 1 per cent. in both cases. Thus the velocity field can be calculated to a high degree of accuracy by making use of vortices and a parabolic velocity distribution.

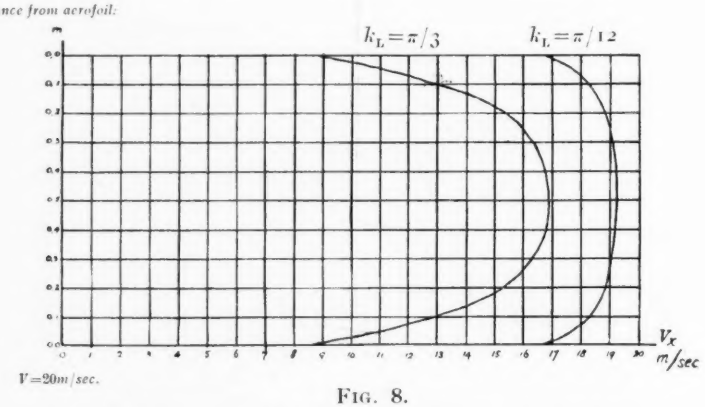

FIG. 8.

The velocity field between two circular-arc aerofoils.

Some further conclusions, applicable to two aerofoils, may now be stated.

CONCLUSION V.—The change in circulation round two aerofoils due to their mutual interference, when separated by at least two chords, may be calculated by replacing them by vortices.

CONCLUSION VI.—The velocity reduction between two aerofoils, for points more than one chord from both aerofoils, can be calculated by treating the aerofoils as vortices, and for points within one chord of one aerofoil by treating the other aerofoil as a vortex and using the parabolic velocity distribution.

CONCLUSION VII.—The velocity reduction between two aerofoils is approximately proportional to the circulation around one of them and to the velocity of the undisturbed stream; it is least midway between them and increases as either is approached; it also increases as the aerofoils are brought closer together.

(e) The Influence of the Gauze Screen

A sheet of gauze between two aerofoils will experience a drag which depends on the velocity field set up by them. The gauze will also influence the flow past the aerofoils by changing the streamline configuration.

Consider the case indicated in Fig. 9 with axes as shown. We will provisionally assume $a \geqq h+c$, so that for points in the gauze the aerofoils may be considered as vortices.

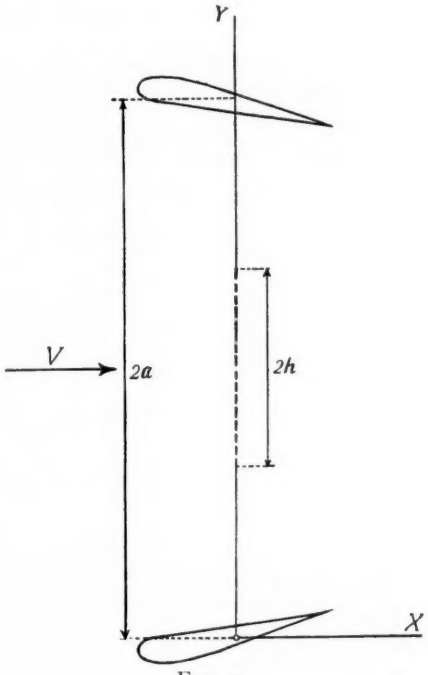

FIG. 9.

The drag per unit breadth of the gauze is, from (8*a*),

$$f = \tfrac{1}{2}k\rho\,(V-u'+u)^2 \quad . \quad . \quad . \quad . \quad . \quad (8a)$$

As mentioned in the note on p. 889, we take an elementary source dQ to represent an element of the gauze dy, giving

$$dQ = f dy/\rho\,(V-u'+u) = \tfrac{1}{2}k\,(V-u'+u)\,dy$$

From (6*a*) and (7*a*) we have

$$u = -f/2\rho\,(V-u'+u) = -\tfrac{1}{4}k\,(V-u'+u) \quad . \quad . \quad (29)$$

and so

$$u = -\{\tfrac{1}{4}k/(1+\tfrac{1}{4}k)\}\,(V-u') \quad . \quad . \quad . \quad . \quad (30)$$

$$f = \{\tfrac{1}{2}k/(1+\tfrac{1}{4}k)^2\}\,\rho\,(V-u')^2 \quad . \quad . \quad . \quad . \quad (31)$$

$$dQ = \{\tfrac{1}{2}k/(1+\tfrac{1}{4}k)\}\,(V-u')\,dy \quad . \quad . \quad . \quad (32)$$

When the aerofoils are absent, so that $u'=0$, (31) becomes the ordinary equation

$$f_0=\tfrac{1}{2}k_1\rho V^2$$

so that

$$k/(1+\tfrac{1}{4}k)^2=k_1{}^*$$

from which

$$k=(4/k_1)\{2-k_1-2\sqrt{(1-k_1)}\} \quad . \quad . \quad . \quad (33)$$

(32) becomes

$$dQ=\{1-\sqrt{(1-k_1)}\}(V-u')\,dy \quad . \quad . \quad . \quad (34)$$

For simplicity writing k_v for the coefficient and V_x for $(V-u')$, the source strength becomes

$$dQ=k_vV_xdy \quad . \quad . \quad . \quad . \quad . \quad (34a)$$

The vertical velocity component v at the point x_1y_1 due to the whole distribution of sources from $y=a-h$ to $y=a+h$ is now given by the integral

$$v=(k_v/2\pi)\int_{a-h}^{a+h}V_x(y_1-y)\,dy/\{x_1{}^2+(y_1-y)^2\}$$

If Γ_1 is the circulation round an aerofoil with the gauze present, then, from (25) we may write:—

$$v=k_v/2\pi\int_{a-h}^{a+h}\{V-a\Gamma_1/\pi(2a-y)\,y\}(y_1-y)/\{x_1{}^2+(y_1-y)^2\}\,dy \quad . \quad (35)$$

At one of the aerofoils, where $y_1=2a$, v varies along the chord from $c^2/4$ for $x_1=\pm c/2$ to zero for $x_1=0$. The influence of the interference flow will, however, be most marked at the leading and trailing edges, so that the velocity v for $x_1{}^2=c^2/4$, for which we will write $4b^2$ may be regarded as the exact interference velocity. We find,

$$\begin{aligned} v=k_vV/4\pi\,[&\log\{4b^2+(a+h)^2\}/\{4b^2+(a-h)^2\} \\ &-a\Gamma_1/2\pi(a^2+b^2)\,V\{\log(a+h)/(a-h) \\ &+\tfrac{1}{2}\log\{4b^2+(a+h)^2\}/\{4b^2+(a-h)^2\} \\ &+a/b\,[\tan^{-1}(a+h)/2b-\tan^{-1}(a-h)/2b]\}] \quad . \quad . \quad (36) \end{aligned}$$

With a small error this may be written

$$\begin{aligned} v\cong(k_vV/4\pi)\,[&(1-\Gamma_1/2\pi aV)\log\{(a+h)^2+4b^2\}/\{(a-h)^2+4b^2\} \\ &-2h\Gamma_1/\{\pi V(a^2-h^2+4b^2)\}] \quad . \quad . \quad . \quad . \quad (37) \end{aligned}$$

There will also be an interference flow v' near the aerofoils in an axial direction. Owing, however, to the symmetry of the field with regard to the ordinate, for $y_1=2a$ we find

$$\int_{-c/2}^{+c/2}v'dx_1=0.$$

This means that the average axial velocity near the aerofoils remains unchanged, so that the presence of the gauze merely changes the direction of the flow at the section. Calling the angle of incidence relative to the x axis α and that relative to the local flow $\alpha+\beta$ then

$$\tan\beta=v/(V-\Gamma_1/4\pi a),$$

or

$$\begin{aligned} \tan\beta=(k_v/4\pi)\,[&(1-\Gamma_1/4\pi aV)\log\{(a+h)^2+4b^2\}/\{(a-h)^2+4b^2\} \\ &-2h\Gamma_1/\pi V(a^2-h^2+4b^2)] \quad . \quad . \quad . \quad . \quad (38) \end{aligned}$$

Inserting the value of Γ from (23) we have

$$\begin{aligned} \tan\beta\cong k_v/4\pi\,[&(1-\Gamma_0/(4\pi aV+\Gamma_0))\log\{(a+h)^2+4b^2\}/\{(a-h)^2+4b^2\} \\ &-8ah\Gamma_0/\{(4\pi aV+\Gamma_0)(a^2-h^2+4b^2)\}] \quad . \quad . \quad . \quad (38a) \end{aligned}$$

* This formula differs from that derived from (9) $k/(1+\frac{1}{2}k)=k_1$ only by the term $[1/4]k^2$ in the denominator, which can be regarded as a quantity of the third order.

Γ_0 now represents the circulation around the section at the original velocity V and the angle of incidence $\alpha+\beta$.

With the help of (38*a*) β_1 and hence the circulation can be readily approximated. By putting, for instance,

$$\tan\beta=(k_v/4\pi)\log\{(a+h)^2+4b^2\}/\{(a-h)^2+4b^2\}$$

Using this first approximate value of β we calculate a second from (38*a*). The true value will be intermediate between these approximate values, at least when the aerofoil is not stalled.

In substituting in (38*a*) the value $\Gamma_0=k_L cV$ we find that β is independent of the velocity of the potential flow.

In the case of a wide gauze screen, *i.e.*, removing the condition $a \geqq h+c$, (37) and (38) are no longer exact; the interference velocity v will be higher than the value given by (37) owing to the greater resistance of the edges, where the prevailing velocities are larger than $V-a\Gamma_1/\pi(2a-y)y$. The differences are so small, however, that (37) may be used in this case also.

It is possible that the gauze, even if narrow, may stall the aerofoils by the change of incidence which it produces, and to restore the circulation again it is necessary to reduce α. If $\alpha=\alpha_{max}$ the aerofoil must be turned through the angle β which can be obtained directly from (38*a*) if Γ_{max} is substituted for Γ_0.

Before the following conclusions were drawn from the formulæ, the value of β was found for circular arc sections by conformal transformation. The values so found obviously do not differ much from those derived from (38*a*).

We may now write:—

Conclusion VIII.—The gauze screen produces at the aerofoil an interference velocity normal to the direction of the stream which increases the incidence of the aerofoils.

Conclusion IX.—By decreasing the incidence of the aerofoils the interference of the gauze on the circulation can be neutralised.

The latter conclusion is of paramount importance in calculating the drag of a gauze screen between two aerofoils. It may be concluded that the influence of the gauze on the aerofoils and hence on the velocity field may be ignored in drag calculations provided the sections are rotated through a certain angle.

(f) The Drag of the Gauze Screen

Let the drag per unit length of the gauze of breadth $2h$ in a uniform stream be

$$w_0=k_1\rho V^2h$$

The drag of the gauze between two aerofoils is, from (31),

$$w=\tfrac{1}{2}k_1\rho\int_{a-h}^{a+h}(V-u')^2\,dy \qquad . \quad . \quad . \quad . \quad (39)$$

or, as u' is small compared with V,

$$w\cong\tfrac{1}{2}k_1\rho\int_{a-h}^{a+h}(V^2-2u'V)\,dy$$

$$=w_0-k_1\rho V\int_{a-h}^{a+h}u'dy$$

Substituting the velocity reduction from (25) we find,

$$w=w_0-k_1\rho V\int_{a-h}^{a+h}a\Gamma dy/\pi(2a-y)y$$

or

$$w=w_0\{1-(\Gamma/\pi hV)\log(a+h)/(a-h)\} \qquad . \quad . \quad (40)$$

Without the foregoing approximation the integral in (39) is

$$w = w_0 \left[1 - (\Gamma/2\pi hV) \{ 2 \log (a+h)/(a-h) - (\Gamma/2\pi aV) [2ah/(a^2-h^2) + \log (a+h)/(a-h)] \} \right] \quad . \quad . \quad (41)$$

Equation (41) holds in all cases where $h \leqq a-c$. When $a > h > a-c$ it gives too small a value, and then (39) must be integrated numerically with the aid of the parabolic velocity distribution.

From the drag formulæ as well as from the character of the velocity field under an aerofoil it will be clear, however, that although the velocity beneath the section decreases much less rapidly than beneath a vortex of the same strength the velocity fields have the same properties in both cases, and that the factors governing the drag reduction are the same. The conclusions drawn from (40) and (41) will therefore, with slight correction, apply to a gauze screen wider than $2a-2c$. These conclusions are:—

Conclusion X.—In the field between two aerofoils, a gauze screen some distance from them undergoes a drag reduction proportional directly to the circulation and inversely to the velocity of the stream, but it increases considerably if the aerofoils are brought nearer to the screen.

Conclusion XI.—The percentage reduction in drag is independent of the velocity of the uniform stream, and the geometrical scale of the system.

In order to form some idea of the drag reduction to be expected, calculations were made, for two cases, from equation (39), in which $V-u'=V_x$ was found from (25) to (27a). The results are given in Tables 1 and 2.

TABLE 1.

Reduction in Drag of a Gauze Screen between Two Circular Arc Aerofoils, as a Function of the Breadth of the Screen.

Breadth of gauze screen (metres).	w_0 kg.	w kg.	Drag Reduction %
1.00	18.750	16.231	13.43
0.90	16.875	14.875	11.85
0.80	15.000	13.412	10.59
0.70	13.125	11.861	9.63
0.60	11.250	10.242	8.96
0.50	9.375	8.577	8.51
0.40	7.500	6.884	8.21
0.30	5.625	5.175	8.01
0.20	3.750	3.455	7.87
0.10	1.875	1.729	7.79
0.01	0.1875	0.1730	7.76

$2a=1$ metre. Depth of section $=0.01$ m. Chord section $=0.24$ m.
$\rho=0.125$. $V=20$ m./sec. $k_L=\pi/12=\pm 0.2618$.
$k=0.75$. $k_v=0.50$.

If the reduction in drag were proportional to Γ/V, or to k_L, then for the case $k_L=\pi/12$ the figures in the last column would have been exactly a quarter of those for $k_L=\pi/3$. The deviations from this ratio are seen to be small.

From these calculations an idea may also be obtained of the effect of changing the distance between the aerofoils. Thus, if the percentage reduction in drag is known when the distance is $2a$, the screen breadth $2h$ and the circulation Γ, then from (40) when the distance between the aerofoils and the breadth of screen are halved while Γ remains the same, it will be approximately doubled.

The effect of varying the distance between the aerofoils will be considered in conjunction with the experimental results.

TABLE 2.

Breadth of gauze screen (metres).	w_0 kg.	w kg.	Drag Reduction %
1.00	18.750	10.602	43.5
0.90	16.875	10.131	40.0
0.80	15.000	9.466	36.9
0.70	13.125	8.617	34.3
0.60	11.250	7.608	32.4
0.50	9.375	6.475	30.9
0.40	7.500	5.255	29.9
0.30	5.625	3.981	29.2
0.20	3.750	2.671	28.8
0.10	1.875	1.341	28.5
0.01	0.1875	0.1343	28.4

$2a = 1$ metre. Depth of section $= 0.04$ m. Chord section $= 0.24$ m.
$\rho = 0.125$. $V = 20$ m./sec. $k_L = \pi/3 = \pm 1.047$.
$k = 0.75$. $k_v = 0.50$.

(g) The Towing Force on the Aerofoils

The force per unit length acting on the aerofoils in an upstream direction may be approximately found from equations (18) and (38) as

$$T = (k_L k_v D - k_{D0})\, \rho\, (V - \Gamma/4\pi a)^2\, c \qquad . \qquad . \qquad . \qquad (42)$$

in which D is a function of a, h and Γ.

As k_v increases more rapidly than the drag coefficient of the gauze, T will also increase more rapidly than the drag coefficient of the gauze. Hence:—

Conclusion XII.—The towing force on the aerofoils is not quite proportional to the drag of the gauze, but increases more rapidly.

(h) The Effect of Changing the Axial Position of the Screen

If the gauze is moved downstream through a distance g from the plane of the vortices it will be situated in a field given by the following equation

$$V_x = V - y\Gamma/2\pi\,(g^2 + y^2) - (2a - g)\,\Gamma/2\pi\,\{\,g^2 + (2a - y)^2\,\}$$

in which the origin is taken in one vortex and the axis of y passes through the other. This equation shows that V_x increases when g increases. Thus any displacement of the gauze from the plane of the vortices reduces the drag reduction, and does so more markedly the greater the displacement. If, however, g is small compared with $a - h$ the change will be very small.

These considerations apply to aerofoils also provided the effect of the screen on the circulation is taken into account. Generally speaking, a displacement of the screen downstream will not have exactly the same effect as a displacement upstream.

With aerofoils having an arbitrary pressure distribution the most favourable situation for the screen will depend upon this pressure distribution. The maximum reduction in drag will usually be found to occur when the screen is placed in the neighbourhood of the leading edge. In this case also the change in drag reduction with displacement of the screen will be small.

Chapter III.

Experimental Results

(a) Description of Apparatus and Tests

To test the foregoing theory, measurements were made in the square-sectioned tunnel at the Laboratory for aero- and hydrodynamics of the Delft Technical High School of the drag of a gauze screen suspended between two

aerofoils. The gauze was composed of wires of 0.6 mm. diameter with a pitch of 4.25 mm.; the screen was 100 mm. in breadth and 792 mm. in length. The tunnel was 800 mm. in width, so that there was a clearance of 4 mm. at each end of the gauze, which was assumed to have no influence on the flow. The gauze was strengthened by a suitable skeleton framework to prevent deflection. It consisted of a central spar with three cross pieces all of streamline section, and was considered not to affect the drag of the gauze appreciably. The wind speed was 26.5 metres (86ft. per second).

The section chosen for the aerofoils was No. 386 in "Ergebnisse der Aerodynamischen Versuchsanstalt zu Göttingen, Lieferung 1."* The following tests were made:—

(1) The drag of gauze screen was measured with the aerofoils at various angles of incidence and various distances apart.
(2) The vertical and horizontal forces on the aerofoils.
(3) Energy measurements.

Fig. 10 is a sketch of the gauze as mounted for test. It was supported by wires from the roof of the tunnel, and stabilised by freely hanging weights. The drag was measured by means of an inclined wire 0.19 mm. in diameter.

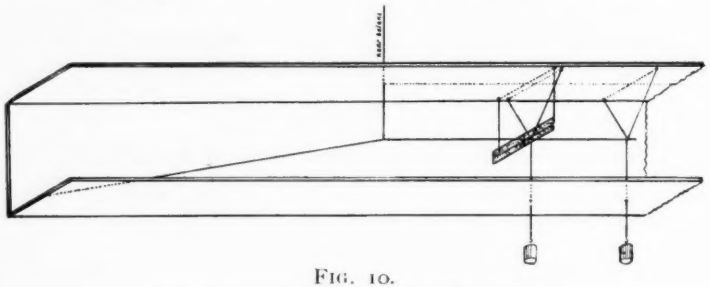

FIG. 10.
Gauze screen mounted in wind tunnel.

The balance was carefully calibrated before and after test; suitable corrections were also determined for the drag of supporting gear.

The aerofoils spanned the tunnel and were adjustable from outside.

Measurements were made with the gauze in three axial positions, namely, 1.5 mm. in front of the plane of the leading edges of the aerofoils, 8.5 mm. and 18.5 mm. behind it. Repeat observations were made for points near minimum drag.

The force on one aerofoil was measured by supporting it from wires and attaching it to lift and drag balances alternately.

The energy measurements behind the gauze were made with pitot tubes. Tubes were placed both behind a wire and behind the space between the wires, and several readings were taken in each case.

From these readings values were obtained of the undisturbed velocity head $q_0 = \frac{1}{2}\rho V^2$, the difference in total head $(P_0 - P)$ between the undisturbed flow and that between the aerofoils, and the change in static pressure $(p - p_0)$. The velocity head $q = \frac{1}{2}\rho V_x^2$ at a point between the aerofoils was found as the difference between $q_0 = \frac{1}{2}\rho V^2$ and $(P_0 - P) + (p - p_0)$. As these differences are small they could be measured with greater accuracy than would be possible with a direct measurement of q. Values of the velocity are given in Table 3 and Fig. 11, use being made of equation (25) for points more than one chord away from the aerofoils.

* Dimensions published in Erge. Aerod. Vers. Göttingen III., 1927, p. 28.

Test Results

1. *Velocity Field between the Aerofoils with Gauze Screen Removed*

For this test the aerofoils were 112 mm. apart, at an angle of incidence relative to the tunnel axis of 3° 20′, which was just below the stall (see Fig. 15), the value of k_L being 0.58.

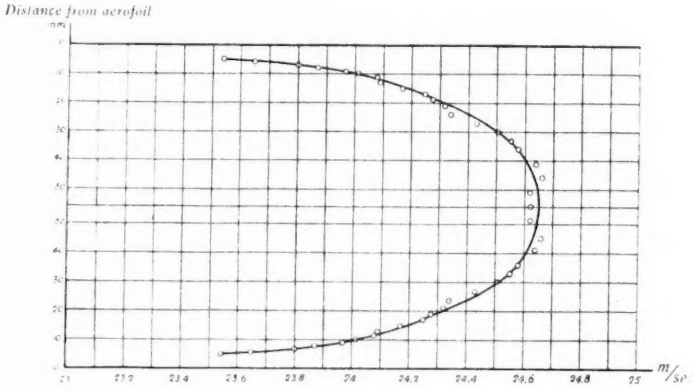

Fig. 11.

Velocity field between two aerofoils.
Aerofoils 112 mm. apart.
Incidence 3° 20′ relative to tunnel axis.
$k_L = 0.58$. $V = 26.53$ *metres/sec.*

TABLE 3.

Observed Velocities.

Distance from Aerofoil (mm.)	V_x in m./sec.	Distance from Aerofoil (mm.)	V_x in m./sec.	Distance from Aerofoil (mm.)	V_x in m./sec.	Calculated Velocities. V_x in m./sec.
5	23·54	13	24·09	30	24·51	23·27
6	23·65	15	24·17	33	24·55	23·45
7	23·80	17	24·25	36	24·58	23·60
8	23·87	19	24·28	41	24·64	23·77
9	23·97	21	24·32	46	24·66	23·89
10	24·01	24	24·34	51	24·62	23·95
11	24·08	27	24·43	56	24·62	23·97

Aerofoils 112 mm. ($=2a$) apart.
$k_L = 0.58$. $c = 0.03$ m. $V = 26.53$ m./sec.

In view of the considerable difference between the observed and calculated velocities shown in the table the use of equation ($27a$) was abandoned. The calculated values apply to an infinite stream and the constriction due to the thickness of the aerofoils, 6 mm. each, probably accounts for part of the difference.

2. *Measurements of the Drag of the Gauze in Relation to the Lift on the Aerofoils*

Length of gauze ... 792 mm.
Height of gauze ... 100 mm.
Velocity ... ... 26.53 m./sec.

$q_0 = \frac{1}{2}\rho V^2 = 44$ kg./m.^{2}.
Drag of gauze alone $w_0 = 2089$ grams.
$k_D = 0.300$.

The drag of the gauze when the aerofoils are present is given in Table 4, and plotted in Figs. 12, 13 and 14. The corresponding variation of k_L of the aerofoil section in free air is given in Fig. 15.

TABLE 4.

DRAG OF SCREEN FOR VARIOUS AEROFOIL POSITIONS.

	Measured Drag (grams).								
	Series 1. 2a in mm.				Series 2. 2a in mm.			Series 3. 2a in mm.	
α (degs.)	112	142	192	282	112	142	192	142	192
−10	2067	2071	2087	2109	2092	2117	2106	2070	2140
−8	1993	2023	2055	2086	2016	2050	2074	2026	2101
−6	1937	1978	2021	2061	1940	2021	2043	1976	2075
−4	1881	1929	1988	2035	1885	1953	2012	1932	2051
−2	1825	1893	1960	2016	1821	1890	1968	1895	2022
−1	1802	1864	—	—	—	1895	—	1873	1998
0	1820	1839	1931	1992	1755	1859	1944	1893	1988
1	1846	1840	1923	1987	—	1835	—	1842	1977
2	1909	1870	1917	1986	1881	1864	1931	1894	1970
3	—	—	1935	1985	—	1880	—	—	2008
4	2008	1966	1963	2004	1934	1924	1993	1996	2039
6	1995	1981	2009	2031	1919	1965	2022	2028	2070
7	1948	1975	2014	—	—	—	—	2034	—
8	1914	1946	2006	2051	1853	1958	2019	1996	2082
9	1932	1916	2006	2052	—	1914	—	1962	2058
10	1957	1940	1986	2043	1807	1880	1980	2000	2045

Series 1.—Gauze 8.5 mm. behind leading edge of aerofoils.
Series 2.—Gauze 1.5 mm. in front of leading edge of aerofoils.
Series 3.—Gauze 18.5 mm. behind leading edge of aerofoils.
$V = 26.53$ m./sec. $w_0 = 2089$ grams.

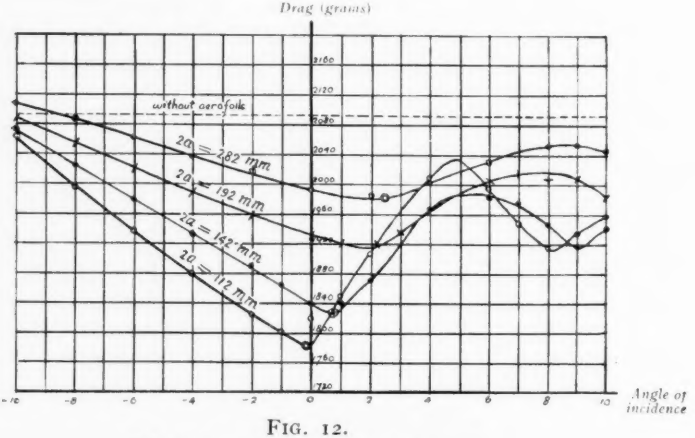

FIG. 12.
Effect of aerofoils on drag of gauze.

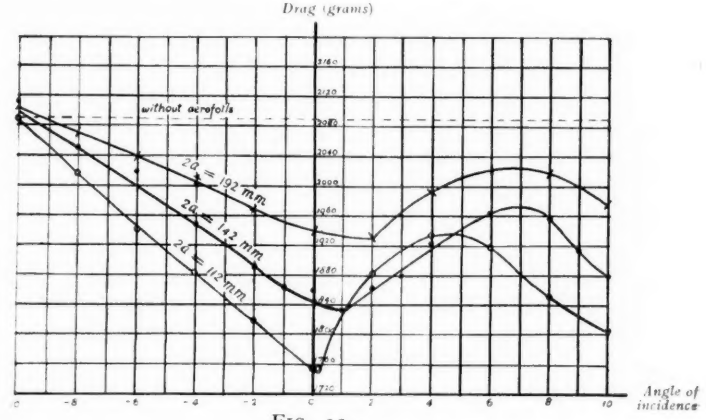

FIG. 13.

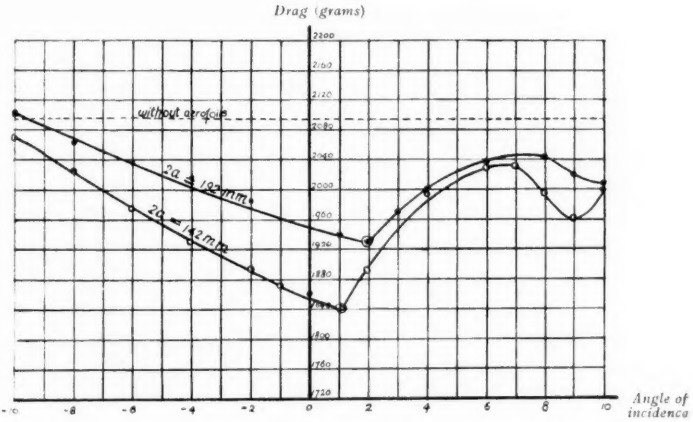

FIG. 14.

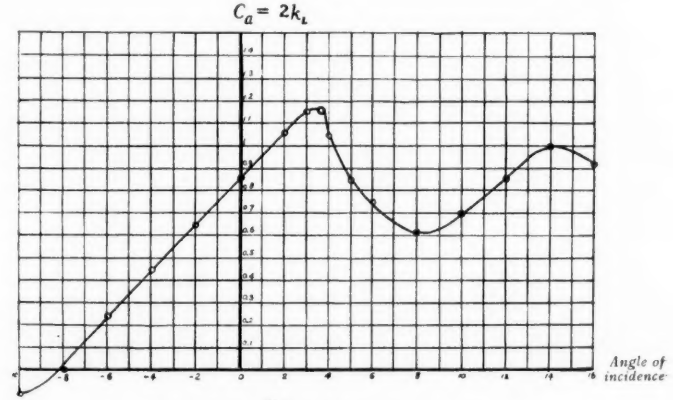

FIG. 15.
Lift coefficient of aerofoil alone.

The curves show a consistent dependence of the drag on the position and lift coefficient of the aerofoils. In particular, that there is practically no change in drag near zero lift, while the reduction in drag increases and decreases in step with the lift coefficient, except for some correction to the angle of incidence. This may be interpreted as induced by the gauze itself producing an inclination β in the flow over the aerofoil. The lift coefficient is not identical with that given in the Göttingen report,† no doubt due to slight errors in reproducing the section, and probably also to the lower Reynolds number.

The close relation between drag reduction and lift coefficient are very clearly shown in Figs. 16, 17 and 18, in which the coefficient k_L,* given in Table 6 and calculated from Table 5, is the lift coefficient measured in the presence of the gauze. Thus if L^* is the vertical force on the aerofoil and D the drag

$$L^* = L\cos\beta + D\sin\beta$$
$$k_L^* = k_L\cos\beta + k_{D0}\sin\beta \quad . \quad . \quad . \quad . \quad (43)$$

Since β is small, and k_{D0} always much less than k_L, k_L^* will be closely equal to k_L when comparing k_L^* at an angle α with k_L at an angle $\alpha+\beta$.

The figures show that k_L^* has a higher maximum value than k_L. As the tunnel velocity was controlled far upstream, the extra constriction caused by introducing the screen and the second aerofoil increases the velocity at the aerofoil, causing higher forces. A similar, though smaller, effect would occur in an infinite stream.

TABLE 5.

	One Aerofoil Alone.	L^* 1		2	One Aerofoil Alone.	W^* 1
α (degs.)	L	2a = 112mm.	2a = 282mm.	2a = 112mm.	W	2a = 112mm.
− 10	− 118	511	73	307	108.5	4.0
− 8	2	736	304	489	62.1	− 21.3
− 6	254	895	550	688	45.2	− 36.0
− 4	463	1053	749	902	38.4	− 43.9
− 2	672	1207	965	1088	35.6	− 45.6
− 1	—	1301	—	—	—	—
0	902	1317	1158	1290	37.6	34.8
1	1045	—	—	848	—	—
2	1121	902	1344	704	43.1	118.7
3	1191	—	1136	—	—	—
4	1100	743	906	628	54.7	170.7
5	887	—	—	—	—	—
6	774	853	735	719	139.5	178.2
8	643	1166	811	1080	185.4	160.4
10	729	1177	940	1172	222.1	273.4
12	881	—	—	—	260.7	—
14	1038	—	—	—	270.4	—
16	961	—	—	—	343.8	—
18	—	—	—	—	407.5	—

Length of aerofoil 0.792 m. $V = 26.53$ m./sec.
Chord of aerofoil 0.03 m. $q = 44$ kg./m.^{2}.

Col. 1 = gauze 8.5 mm. behind leading edge of aerofoils
Col. 2 = gauze 1.5 mm. in front of leading edge of aerofoils.

† loc. cit.

TABLE 6.

		$2k_L{}^*$		
	One Aerofoil Alone.	1		2
α (degs.)	$2k_L$	2a=112mm.	2a=282mm.	2a=112mm.
−10	−0.113	0.489	0.070	0.294
−8	0.002	0.704	0.291	0.468
−6	0.243	0.856	0.520	0.658
−4	0.443	1.007	0.716	0.863
−2	0.643	1.155	0.923	1.041
−1	—	1.244	—	—
0	0.863	1.260	1.108	1.234
1	1.000	—	—	0.811
2	1.072	0.863	1.286	0.673
3	1.139	—	1.087	—
4	1.052	0.711	0.867	0.601
5	0.848	—	—	—
6	0.740	0.816	0.703	0.688
8	0.615	1.115	0.776	1.033
10	0.697	1.126	0.869	1.121
12	0.843	—	—	—
14	0.993	—	—	—
16	0.919	—	—	—

$k_{L\max}=0.585$ at $\alpha=3^\circ\ 45'$ (see Fig. 15).

$V=26.53$ m./sec. $\qquad q=44$ kg./m.^{2}.

Col. 1 = gauze 8.5 mm. behind leading edge of aerofoils.

Col. 2 = gauze 1.5 mm. in front of leading edge of aerofoils.

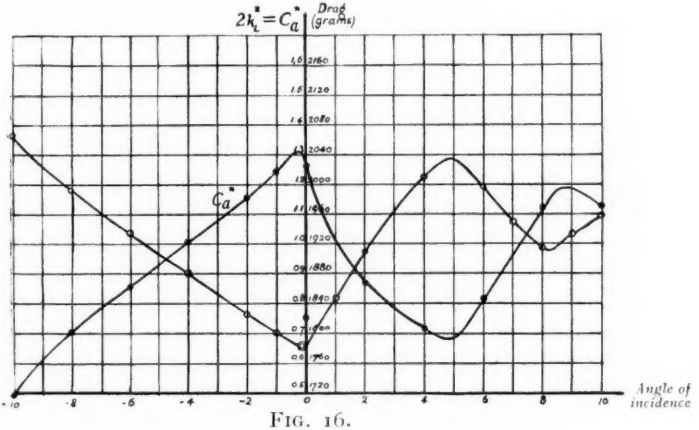

FIG. 16.

Relation between lift of aerofoils and drag of screen.
Gauze screen 8.5 mm. behind leading edge of aerofoils.
Aerofoils 112 mm. apart.

From the theory it was deduced that the influence of the gauze on the aerofoils was merely to induce a vertical velocity, which could be neutralised by swivelling the aerofoils in order to restore the circulation to its original value. However, the theory neglected the thickness both of the aerofoils, and of the wires of the gauze, and it is this thickness which causes the velocity increment, and with it the circulation increment.

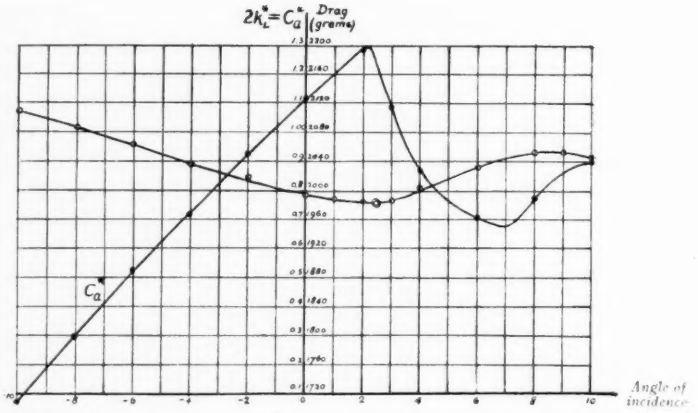

FIG. 17.

Relation between lift of aerofoils and drag of screen. Gauze screen 8.5 mm. behind leading edge of aerofoils. Aerofoils 282 mm. apart.

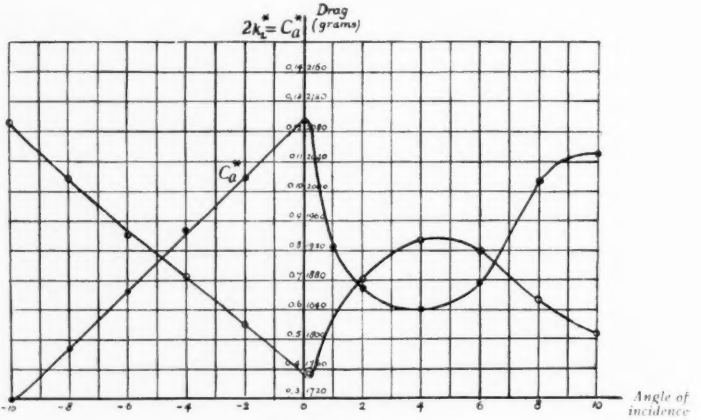

FIG. 18.

Relation between lift of aerofoils and drag of screen. Gauze screen 1.5 mm. in front of leading edge of aerofoils. Aerofoils 112 mm. apart.

A similar argument shows that the aerofoils, if adjusted to zero circulation, will by their thickness only, increase the drag of the gauze. Hence the aerofoils will have to be adjusted to a positive circulation to reduce the gauze drag to its initial value. These features are shown by the observations in the figures.

Now an increase in the gauze drag is equivalent to a reduction in lift coefficient of the aerofoils. This tends to balance the increase in lift coefficient due to the presence of the gauze, so that in calculating the drag reduction, the thickness may be neglected, and the theoretical formula used.

The curves also show that the drag reduction does not depend very much on the axial position of the gauze relative to the aerofoils, as predicted in Chapter II. The greatest reduction (16 per cent.) was obtained with the gauze just in front of the leading edge, but is only slightly greater than when 8.5 mm. behind.

The average reductions, at the three axial positions, will now be compared with the values for different distances apart of the aerofoils, calculated from equation (39). The reduction in resistance is

$$(w_0 - w)/w_0 = (1/2h)\int_{a-h}^{a+h}[1-(V-u'/V)^2]\,dy,$$

where V and u' are the values measured at a distance apart of $2a = 112$ mm. given in Table 3.

By numerical integration we find

$$(w_0 - w)/w_0 = 15.3\%$$

which agrees well with the observed value at the same value of $2a$.

For points where $a - h > c$ we can compare the results with (41). As the measured reductions are less than those calculated, no calculations have been made where the parabolic distribution would have to be used. Formula (10) has been used throughout and the circulation found from (23*a*) taking the value 0.58 as the maximum value of k_L. The results are shown in Table 7.

TABLE 7.

COMPARISON BETWEEN OBSERVED DRAG AND DRAG CALCULATED FROM (10) AND (41).

$2a$ mm.	Observed Drag Reductions (grams). Series 1	Series 2	Series 3	Average	% of w_0	Calculated % of w_0 From (10)	From (41)
112	306	335	—	320	15.3	20	—
142	263	256	247	255	12.2	15.7	—
192	174	155	157	162	7.8	11.6	12.3
282	107	—	—	107	5.1	7.9	8.0

$V = 20.53$ metres/sec.

$k_{L\max} = 0.58$. $c = 0.03$ m. $w_0 = 2089$ grammes. $2h = 0.1$ m.

Although the calculated values are appreciably higher than those observed, there is good general agreement with the predictions of the theory (see Fig. 19).

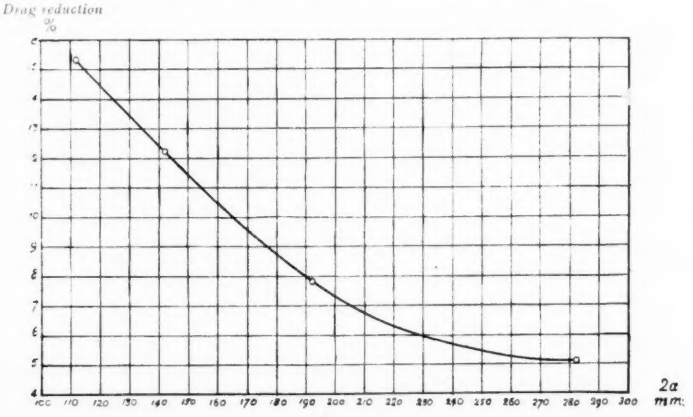

FIG. 19.

Effect of distance apart of aerofoils on drag reduction.

3. *The Change of Incidence Required by the Interference of the Gauze Screen*

The maximum k_L of a single section was measured ($\alpha = 3^\circ\ 45'$), and also the angles at which the drag reduction was greatest. These are given in Table 8.

As before, average values are taken. The difference between $\alpha = 3^\circ\ 45'$ and the average incidence at maximum drag reduction, is the angle β through which the flow has been deflected. The table also contains values calculated from formulæ (17) and (38). In (17) the value $k_1 = 0.60$ was used, from which the value $k_v = 1 - \sqrt{(1 - k_1)} = 0.367$ was found for (38).

TABLE 8.

ANGLES THROUGH WHICH AEROFOILS MUST BE ROTATED AT MAXIMUM DRAG REDUCTION.

2a mm.	Angle for Maximum Drag Reduction. Series 1	Series 2	Series 3	Average	β	β Calculated. Formula (17)	Formula (38)
112	$-10'$	$10'$	—	$0'$	$3^\circ\ 45'$	$4^\circ\ 52'$	$5^\circ\ 06'$
142	$45'$	1°	$1^\circ\ 10'$	$58'$	$2^\circ\ 47'$	$3^\circ\ 51'$	$4^\circ\ 45'$
192	$2^\circ\ 10'$	$1^\circ\ 50'$	$1^\circ\ 50'$	$1^\circ\ 57'$	$1^\circ\ 48'$	$2^\circ\ 51'$	$3^\circ\ 31'$
282	$2^\circ\ 30'$	—	—	$2^\circ\ 30'$	$1^\circ\ 15'$	$1^\circ\ 56'$	$2^\circ\ 22'$

$\alpha = 3^\circ\ 45'$. $k_1 = 0.600$. $k_v = 0.367$.

$2h = 0.1$ m. $k_{L\max} = 0.585$.

The general agreement is fair, although the theoretical values are again considerably higher than the observed values in roughly the same degree as the drag reduction. With many disturbing factors, such as non-homogeneity of the gauze due to the frame, etc., the situation of gauze relative to the leading edges of the aerofoils, etc., closer agreement could perhaps hardly be expected.

Finally, in Fig. 20, the observed changes of incidence for maximum drag reduction are plotted against distance apart of aerofoils.

4. *Axial Forces on the Aerofoils*

In the case in which the gauze was placed 8.5 mm. behind the leading edges of the aerofoils, the axial forces W* on the aerofoils were measured at various

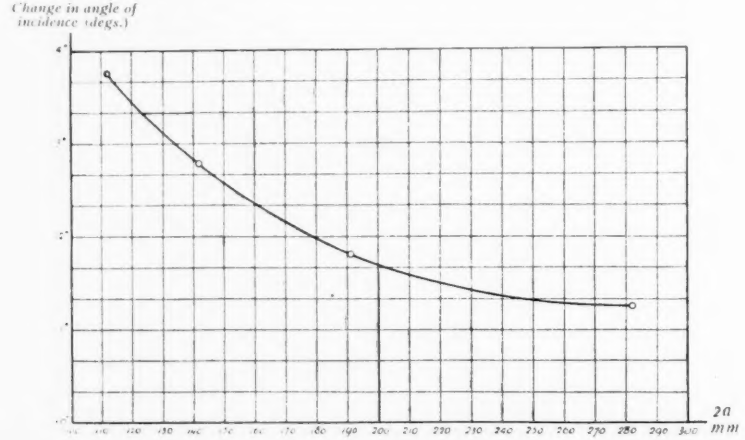

FIG. 20.

Change in incidence for maximum drag reduction, as a function of distance apart of aerofoils.

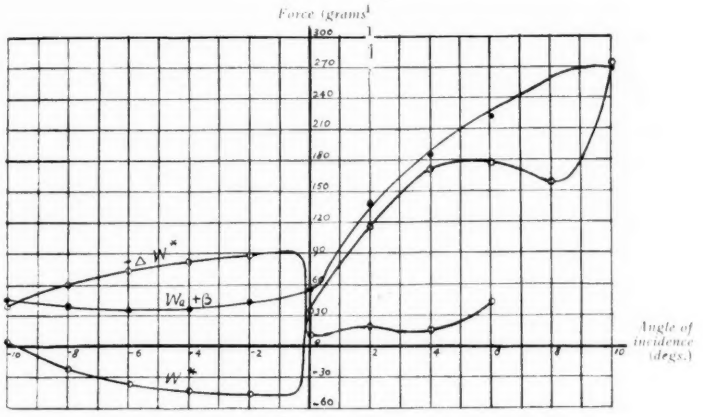

FIG. 21.

Axial forces on aerofoils at different incidences.

incidences. The results are given in Table 5 and Fig. 21. The curves contain the drag of two small tinplates which were placed on the aerofoils in front of the small openings in the tunnel walls through which the studs for carrying the aerofoils projected.

It is clear from the figure that there is a " towing force " acting on the aerofoils over a considerable range of incidence. The curve $-\Delta D^*$ in the same figure, which may be called the gross towing force on the section, is the forward force neglecting the drag of the section, and is calculated from the equation

$$W_\alpha^* - W_{\alpha+\beta} \cos \beta = \Delta W^*$$

in which W_α^* is the drag of the section under the influence of the gauze screen at an angle α, and $W_{\alpha+\beta}$ the drag of the single section at an angle of incidence $\alpha+\beta$. In Table 5, the values of W_α^* and $W_{\alpha+\beta}$ are both increased by the drag of the tinplates. As $\cos \beta$ is nearly unity, this drag is eliminated from ΔW^*. Further, it follows from (38) by supposing $\Gamma=0$, that the change in β when varying Γ, will be small, so that β is approximately independent of α. From Table 8, column 2, $\beta=3^\circ\ 45'+10'$, or 4° nearly at maximum drag reduction of the gauze screen when at 8.5 mm. behind the leading edges of the aerofoils. The aerofoils were 112 mm. apart, which is the distance for which W^* was computed. With this value of β (4°), $W_{\alpha+\beta}$ and ΔW^* can be verified from Table 5 (columns 6 and 7).

The gross towing force $-\Delta W^*$ should also be equal to $L_\alpha^* \tan \beta$, where L_α^* is the lift on the aerofoil in the presence of the gauze. In Table 9 these quantities are compared.

TABLE 9.

α	Wa^*	$Wa+\beta$	$-\triangle W^*$	La^*	$La^* \tan \beta$
-10°	4.0	+45.2	41.2	511	35
-8°	−21.3	38.4	59.7	736	51
-6°	−36.0	35.6	71.6	895	63
-4°	−43.9	37.6	81.5	1053	74
-2°	−45.6	43.1	88.7	1207	84
-0°	+34.8	54.7	19.9	1317	92
$+2^\circ$	118.7	139.5	20.8	902	63
4°	170.7	185.4	14.7	743	52
6°	178.2	222.1	43.9	853	60

3. *The Change of Incidence Required by the Interference of the Gauze Screen*

The maximum k_L of a single section was measured ($\alpha = 3^\circ\ 45'$), and also the angles at which the drag reduction was greatest. These are given in Table 8.

As before, average values are taken. The difference between $\alpha = 3^\circ\ 45'$ and the average incidence at maximum drag reduction, is the angle β through which the flow has been deflected. The table also contains values calculated from formulæ (17) and (38). In (17) the value $k_1 = 0.60$ was used, from which the value $k_v = 1 - \sqrt{(1 - k_1)} = 0.367$ was found for (38).

TABLE 8.

ANGLES THROUGH WHICH AEROFOILS MUST BE ROTATED AT MAXIMUM DRAG REDUCTION.

2a	Angle for Maximum Drag Reduction.					β Calculated.	
mm.	Series 1	Series 2	Series 3	Average	β	Formula (17)	Formula 38)
112	$-10'$	$10'$	—	$0'$	$3^\circ\ 45'$	$4^\circ\ 52'$	$5^\circ\ 06'$
142	$45'$	1°	$1^\circ\ 10'$	$58'$	$2^\circ\ 47'$	$3^\circ\ 51'$	$4^\circ\ 45'$
192	$2^\circ\ 10'$	$1^\circ\ 50'$	$1^\circ\ 50'$	$1^\circ\ 57'$	$1^\circ\ 48'$	$2^\circ\ 51'$	$3^\circ\ 31'$
282	$2^\circ\ 30'$	—	—	$2^\circ\ 30'$	$1^\circ\ 15'$	$1^\circ\ 56'$	$2^\circ\ 22'$

$\alpha = 3^\circ\ 45'$. $k_1 = 0.600$. $k_v = 0.367$.

$2h = 0.1$ m. $k_{L\max} = 0.585$.

The general agreement is fair, although the theoretical values are again considerably higher than the observed values in roughly the same degree as the drag reduction. With many disturbing factors, such as non-homogeneity of the gauze due to the frame, etc., the situation of gauze relative to the leading edges of the aerofoils, etc., closer agreement could perhaps hardly be expected.

Finally, in Fig. 20, the observed changes of incidence for maximum drag reduction are plotted against distance apart of aerofoils.

4. *Axial Forces on the Aerofoils*

In the case in which the gauze was placed 8.5 mm. behind the leading edges of the aerofoils, the axial forces W^* on the aerofoils were measured at various

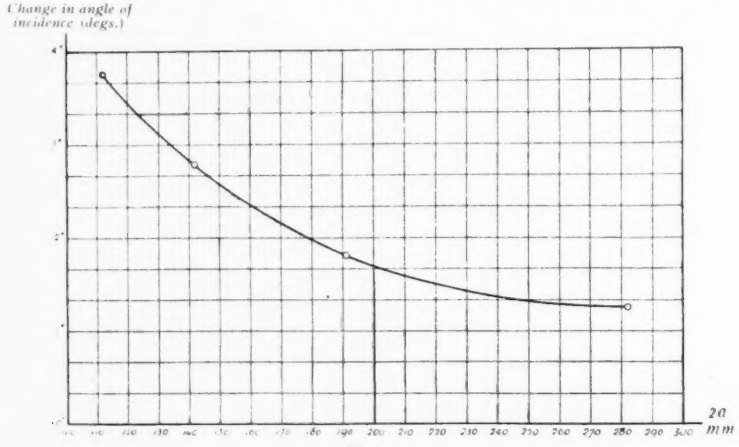

FIG. 20.

Change in incidence for maximum drag reduction, as a function of distance apart of aerofoils.

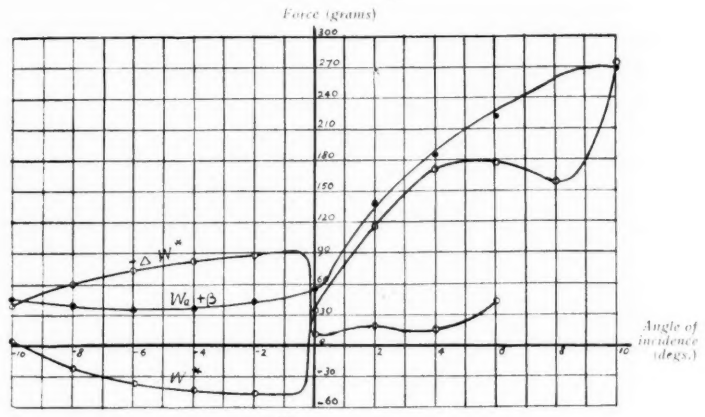

FIG. 21.

Axial forces on aerofoils at different incidences.

incidences. The results are given in Table 5 and Fig. 21. The curves contain the drag of two small tinplates which were placed on the aerofoils in front of the small openings in the tunnel walls through which the studs for carrying the aerofoils projected.

It is clear from the figure that there is a "towing force" acting on the aerofoils over a considerable range of incidence. The curve $-\Delta D^*$ in the same figure, which may be called the gross towing force on the section, is the forward force neglecting the drag of the section, and is calculated from the equation

$$W_\alpha^* - W_{\alpha+\beta}\cos\beta = \Delta W^*$$

in which W_α^* is the drag of the section under the influence of the gauze screen at an angle α, and $W_{\alpha+\beta}$ the drag of the single section at an angle of incidence $\alpha+\beta$. In Table 5, the values of W_α^* and $W_{\alpha+\beta}$ are both increased by the drag of the tinplates. As $\cos\beta$ is nearly unity, this drag is eliminated from ΔW^*. Further, it follows from (38) by supposing $\Gamma=0$, that the change in β when varying Γ, will be small, so that β is approximately independent of α. From Table 8, column 2, $\beta=3^\circ\ 45'+10'$, or 4° nearly at maximum drag reduction of the gauze screen when at 8.5 mm. behind the leading edges of the aerofoils. The aerofoils were 112 mm. apart, which is the distance for which W^* was computed. With this value of β (4°), $W_{\alpha+\beta}$ and ΔW^* can be verified from Table 5 (columns 6 and 7).

The gross towing force $-\Delta W^*$ should also be equal to $L_\alpha^* \tan\beta$, where L_α^* is the lift on the aerofoil in the presence of the gauze. In Table 9 these quantities are compared.

TABLE 9.

α	Wa^*	$Wa+\beta$	$-\triangle W^*$	La^*	$La^* \tan\beta$
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$+2^\circ$	118.7	139.5	20.8	902	63
4°	170.7	185.4	14.7	743	52
6°	178.2	222.1	43.9	853	60

Below the stall the agreement between $-\Delta W^*$ and $L^* \tan \beta$ is fairly good, but beyond it is evident that very large disturbances occur.

5. *The Relation between the Drag Reduction of the Gauze and the Towing Force on the Aerofoils*

It was mentioned in Conclusion II that the towing forces on two vortices was approximately equal to half the reduction in drag of the gauze, while from Conclusion IV it follows that further from the aerofoil than one chord the aerofoil may be treated as a vortex. If we take for the gross towing force of an aerofoil the axial component of the lift, then it follows from both conclusions taken jointly that the drag reduction of a gauze which does not approach within one chord of either aerofoil is approximately equal to twice the sum of the gross towing force of one aerofoil. As a direct measurement was only made for one value of $2a$, we must calculate it from $L \sin \beta$.

Writing again for the drag reduction $w_0 - w$ then

$$w_0 - w \cong 4L \sin \beta.$$

On account of the effect of the thickness of the aerofoils and the wires of the gauze already mentioned, this formula becomes inaccurate for small values of L. If this effect is neglected and L_0 is calculated from the lift coefficient and the undisturbed velocity V, it is best to limit the formula to cases where the maximum drag reduction occurs, and thus:—

$$(w_0 - w)_{\max} = 4L_{0\max} \sin \beta \quad . \quad . \quad . \quad . \quad (44)$$

To what extent does this equation hold when the aerofoils are nearer to the gauze than one chord?

Theoretically this question cannot be immediately answered, but results for such points, calculated from (44), are compared with observation in Table 10, and show agreement down to $2a = 112$ mm. (breadth of gauze, 100 mm.), that is, to within 1/5th of a chord. In this calculation k_L has been taken as 0.58 and the angle of disturbance β from Table 8.

Hence we may write:—

Conclusion XIII.—The maximum drag reduction of a gauze screen between two aerofoils is approximately four times the product of the maximum lift coefficient and the sine of the angle of disturbance.

Conclusion XIV.—Neglecting the drag of the aerofoils, the maximum drag reduction of the gauze screen when the aerofoils are attached to it is approximately $1\frac{1}{2}$ times the maximum drag reduction of the screen when detached.

TABLE 10.

The Observed and Calculated Maximum Drag Reductions of a Gauze Screen between Two Aerofoils.

$2a$ mm.	β (observed) from Table 8.	Max. Drag Reduction (grammes). Observed (Table 7).	Calculated (formula (44)).
112	3° 45′	320	320
142	2° 47′	255	238
192	1° 48′	162	154
282	1° 15′	107	107

$k_{L\max} = 0.58$. $c = 0.03$ m. $l = 0.792$ m. $V = 26.5$ m./sec.

6. *The Momentum Measurements*

As a general check on the results, measurements of momentum were made at a distance of 112 mm. behind the gauze, with and without the aerofoils. The aerofoils, when present, were placed with their leading edges 1.5 mm. behind the gauze, and adjusted to make the drag of the gauze a minimum.

The momentum loss was calculated from the Prandtl-Tietjens formula.† Let w^* be the loss of momentum per unit length of gauze, P_o the total head, q_o the velocity head, and p_o the static pressure in the undisturbed stream and P, q and p their values at the point considered; then the formula is

$$w^* = \int^D (P_o - P)\, dy + \rho/2 \int^D (v_1 - v)\,(v_1 + v - 2V)\, dy \quad . \quad . \quad (45)$$

where $v = \sqrt{\{2(P-p)/\rho\}}$, $v_1 = \sqrt{\{2(P_o-p)/\rho\}}$ and $\int^D$ indicates that integration extends over the region D in which $P < P_o$. Writing the velocities

$$v_1 = \sqrt{\{2(q_o + p_o - p)/\rho\}}, \quad V = \sqrt{(2q_o/\rho)} \text{ and } v = \sqrt{(2q/\rho)}$$

and eliminating them, (45) becomes

$$w^* = \int^D (P_o - P)\, dy + \int^D \{ q_o - q + p_o - p + 2\sqrt{(qq_o)} - 2\sqrt{[q_o(q_o + p_o - q)]} \}\, dy$$

or, since $q = q_o - (P_o - P) + (p_o - p)$

$$w^* = 2\int^D (P_o - P)\, dy - 2\int^D \{ \sqrt{[q_o(q_o + p_o - p)]} - \sqrt{(q_o[q_o - (P_o - P) + (p_o - p)])} \}\, dy \quad . \quad . \quad . \quad (45a)$$

This expresses w^* in quantities which can be easily measured with a pitot and gauge. The results of these measurements are given in Tables 11 and 12, in which H is the local loss of momentum per unit area.

TABLE 11.

VELOCITY FIELD 112 MM. BEHIND GAUZE WITHOUT AEROFOILS.

Distance from centre line of gauze (mm.)	$P_o - P$ kg/m.²	$p_o - p$ kg/m.²	V_x m./sec.	H kg/m.²
65	0.480	7.896	28.68	0.520
60	0.508	8.004	28.70	0.536
55	6.704	8.334	27.02	7.088
50	19.904	9.104	23.07	19.592
45	23.048	9.512	22.08	22.272
40	22.844	9.700	22.22	22.160
35	22.416	9.736	22.39	21.832
30	22.688	9.800	22.31	22.064
25	22.888	9.884	22.27	22.248
20	24.488	10.104	21.77	23.584
15	27.184	10.424	20.87	25.728
10	30.308	10.716	19.76	28.016
5	34.056	11.012	18.31	30.456
0	37.184	11.192	61.97	32.134

$V = 26.53$ m./sec. $\quad H = 2\{(P_o - P) - \sqrt{q_o(q_o + p_o - p)} + \sqrt{q_o q}\}$.

$q_o = 44$ kg./m.². $\quad q = q_o - (P_o - P) + (p_o - p)$.

$$w_1^* = 0.792 \int^D H\, dy = 2074 \text{ grams.}$$

Measurements were made up to a distance of 65 mm. from the centre line; at this point $P_o - P$, though not quite zero, was unimportant. This limitation was necessary to avoid the region where the effects of the resistance of the aerofoils would be present. Any uncertainty on this point is shown by the calculations to affect the results but slightly.

† Hydro und Aeromechanik, Zweiter Band, Berlin, **1931**, p. **143**.

Integration of the results obtained without the aerofoils should yield the drag of the gauze. The figure found for this, from Table 11, is $w_o = 2074$ grams, which agrees very well with the figure measured directly, namely, 2087 grams.

If w_1^* and w_2^* are the momentum losses without and with the aerofoils respectively, we may write, from Conclusion XIV, and from what has been said in Chapter II about momentum losses,

$$w_1^* - w_2^* \cong (3/2)(w_o - w)$$

so that the drag reduction of the gauze is

$$w_o - w \cong (\tfrac{2}{3})(w_1^* - w_2^*) \quad . \quad . \quad . \quad . \quad . \quad (46)$$

As $w_o = w_1^*$, the drag of the gauze between the aerofoils is

$$w = (\tfrac{1}{3})\, w_1^* + (\tfrac{2}{3})\, w_2^* \quad . \quad . \quad . \quad . \quad . \quad (47)$$

whereas according to Conclusion XIII together with (46)

$$4L_{omax} \sin\beta \cong (\tfrac{2}{3})(w_1^* - w_2^*)$$

or for the towing force exerted by one aerofoil (neglecting its own drag),

$$L_{omax} \sin\beta \cong (\tfrac{1}{6})(w_1^* - w_2^*) \quad . \quad . \quad . \quad . \quad . \quad (48)$$

Finally, the overall drag of the gauze with aerofoils attached to it is

$$w - 2L_{omax} \sin\beta = w_2^* \quad . \quad . \quad . \quad . \quad . \quad (49)$$

TABLE 12.

VELOCITY FIELD 112 MM. BEHIND GAUZE WITH AEROFOILS.

Distance from centre line of gauze (mm.)	$P_o - P$ kg/m.²	$p_o - p$ kg/m.²	V_x m./sec.	H kg/m.²
65	0.400	6.100	28.20	0.424
60	0.376	5.976	28.17	0.400
55	4.464	5.988	26.99	4.640
50	8.844	6.136	25.70	9.000
45	13.556	6.416	24.29	13.464
40	18.368	6.644	22.72	17.696
35	18.160	6.680	22.81	17.536
30	18.416	6.676	22.72	17.744
25	19.000	6.676	22.51	18.224
20	20.208	6.836	22.14	19.368
15	22.300	7.100	21.47	20.952
10	25.464	7.436	20.38	23.384
5	28.960	7.736	19.09	25.808
0	31.788	7.964	17.96	27.528

$k_L = 0.58$. $q_o = 44$ kg./m. $V = 26.53$ m./sec.

$c = 0.03$ m. $w_2^* = 0.792 \int_0^D H dy = 1602$ grams.

As a check on equations (46) to (49) comparison is made in Table 13 of the values obtained by direct measurement and those calculated from the momentum losses. The latter involve some uncertainty due to the possibility that part of the drag of the aerofoils is included in the measurements, as mentioned above. They have therefore been calculated for two assumed conditions, one, given in column A, in which no aerofoil drag is considered to be included in the measurements of momentum loss, and the other, in column B, in which the greater part of the aerofoil drag is included. It should be noted that the value $L_{omax} \sin\beta$ in column 2 was calculated from the maximum lift on the single aerofoil and the measured value of β. The difference between the towing force and drag of one aerofoil for an average value of β is 80 grams. The value 76 grams calculated in Table 13 is probably on the low side.

It will be seen that the agreement between the direct measurements and those based upon Conclusions XIII and XIV, relating to momentum measurements, is very good, which again confirms the correctness of the conclusions.

TABLE 13.

	Obtained from direct measurement. grams.	Calculated from momentum loss.	
		A grams.	B grams.
Drag of gauze alone	w_0 2089	w_1 2074	2074
Minimum drag of gauze under influence of aerofoils	w 1754	$w_1/3+2w_2/3$ 1759	1726
Maximum drag reduction of gauze under influence of aerofoils ...	w_0-w 335	$\frac{2}{3}(w_1{}^*-w_2{}^*)$ 315	348
(Towing force) – (aerofoil section drag) under influence of gauze	$L_{0\max}\sin\beta$ 76	$\frac{1}{6}(w_1{}^*-w_2{}^*)$ 79	87
(Minimum overall drag of gauze and aerofoils) – (drag of aerofoil section)	$w-2\,L_{0\max}\sin\beta$ 1602	$w_2{}^*$ 1602	1552

Gauze 1.5 mm. in front of leading edge of aerofoils.
$V=26.53$ m./sec. $k_{L\max}=0.58$. $2a=112$ mm.
$c=0.03$ m. Length of aerofoils 0.792 m. $\beta=3^\circ\ 35'$.

In Figs. 22 to 26 the results of the momentum measurements are plotted.

Figs. 22 to 24 show that with the aerofoils, the losses of total head and of static pressure behind the gauze are less than without them, while the velocity

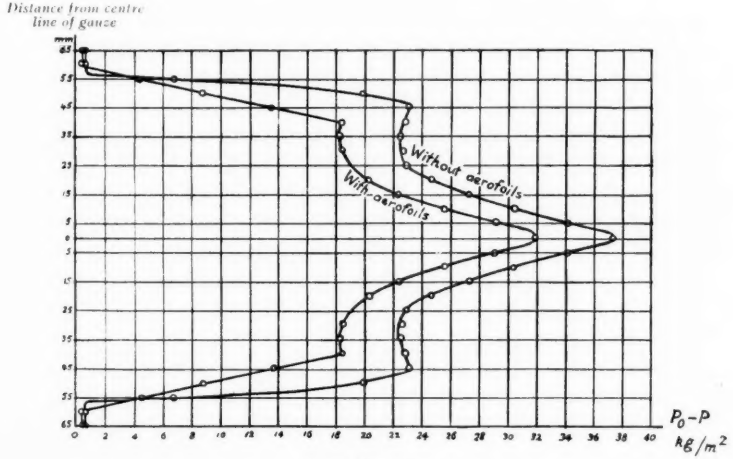

FIG. 22.

Total head 112 mm. behind gauze, with and without aerofoils.

is greater. Fig. 25 gives a good idea of the way in which the turbulent region behind the gauze becomes narrower with the aerofoils present. Finally, Fig. 26

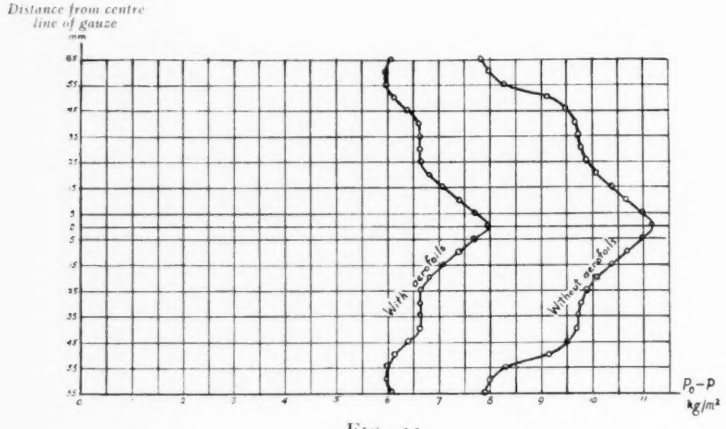

FIG. 23.
Static pressure 112 *mm. behind gauze, with and without aerofoils.*

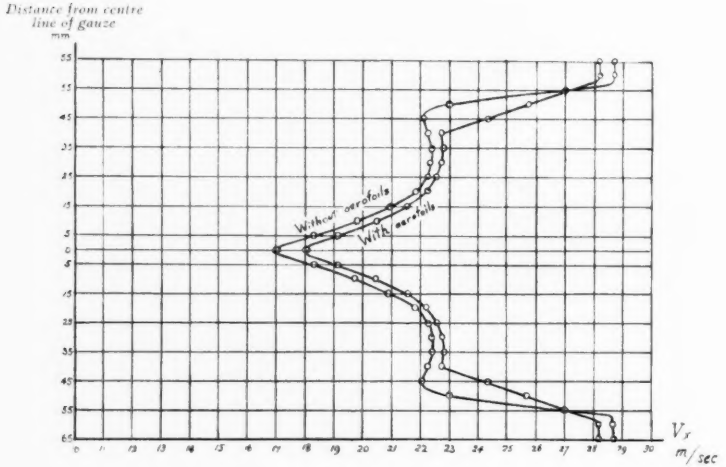

FIG. 24.
Axial velocity components 112 *mm. behind gauze, with and without aerofoils.*
$V = 26.53$ *m./sec.*

illustrates the difference in the measured momentum losses. In this figure the differences in the width of the turbulent layers for the gauze and frame are shown by the kinks in the curve.

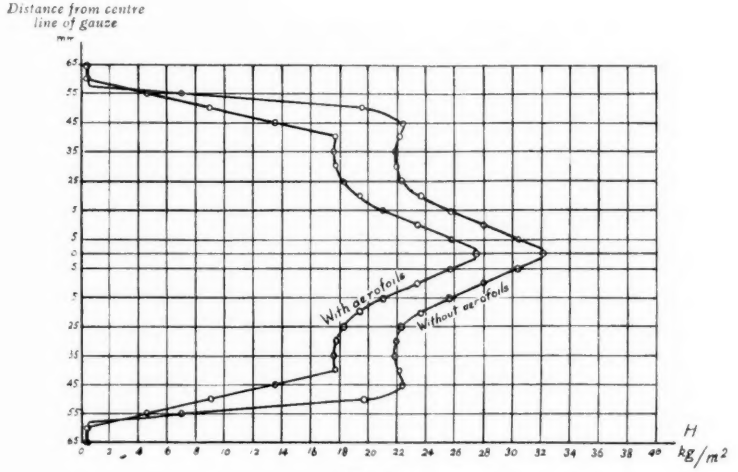

FIG. 25.

Momentum losses 112 *mm. behind gauze, with and without aerofoils.*

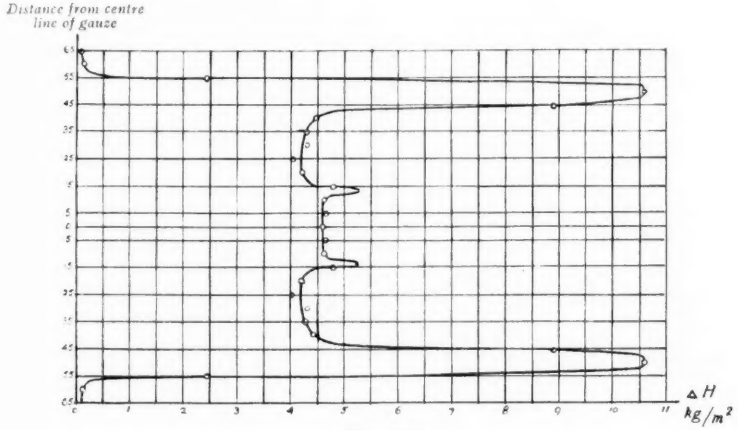

FIG. 26.

Difference in momentum losses 112 *mm. behind gauze, with and without aerofoils.*

CHAPTER IV.

THE TOWNEND RING

Although it would be of great interest to examine the foregoing results to see what practical advantages might be extracted from them we must first extend the theory to three dimensions, that is, to the Townend Ring. The conclusions relating to the ring which correspond with those drawn for the two-dimensional problem will be marked with the same number together with the subscript *a*.

For simplicity we will start by replacing the ring by a single circular vortex.

(a) The Flow round a Gauze Disc under the Influence of a Stationary Circular Vortex: First Approximation

Let us consider a gauze disc of radius h placed in a stream of velocity V and surrounded by a circular vortex of radius a.

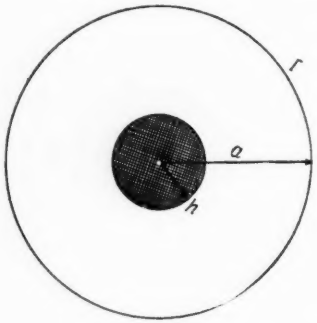

FIG. 27.

Assuming that a is large compared with h the interference velocity u' near the gauze due to the vortex is, as will be derived later, $\Gamma/2a$, and we may write, in accordance with (8*a*),

$$f=\tfrac{1}{2}k\rho\,(V-\Gamma/2a+u)^2 \quad . \quad . \quad . \quad . \quad (50)$$

and since also

$$u\cong -f/2\rho V$$

we find, as in the two-dimensional case,

$$f=f_0\,(1-\Gamma/aV) \quad . \quad . \quad . \quad . \quad . \quad (50a)$$

The quantity of fluid to be forced away, or the strength of the source Q is now,

$$Q\cong -\pi h^2 u_a\cong \pi h^2 f/\rho V$$

and the radial interference velocity v near a vortex element is

$$v=Q/4\pi a^2=h^2 f/4\rho a^2 V \quad . \quad . \quad . \quad . \quad (51)$$

The upstream force acting on the vortex as a result of this flow is

$$K=2\pi a\rho\Gamma v\cong \pi h^2 f\Gamma/2aV \quad . \quad . \quad . \quad . \quad (52)$$

or per unit area of gauze

$$K/\pi h^2=f\Gamma/2aV.$$

Let f^* be the overall drag of gauze and vortex then,

$$f^*\cong f_0\,(1-3\Gamma/2aV) \quad . \quad . \quad . \quad . \quad (53)$$

Formulæ (50), (50*a*) and (53) lead to:—

CONCLUSION I*a*.—When a gauze disc is surrounded by a circular vortex, in the manner considered above, it undergoes a reduction of drag which varies directly as its free-air drag and the strength of the vortex, and inversely as the velocity of the stream and the radius of the vortex.

CONCLUSION II*a*.—The vortex will experience a force urging it against the stream, approximately equal to half the reduction in drag experienced by the gauze disc.

If we regard the Townend Ring as an approximation to a circular vortex, and neglect the mutual interference of the elements of the ring, we find, with the aid of (51), the angle of disturbance of the flow to be given by

$$\tan\beta=v/V=h^2 f/4\rho a^2 V^2=k_1 h/8a^2 \quad . \quad . \quad . \quad (54)$$

For the towing force on the ring we find

$$T = 2\pi a\,(k_{\mathrm{L}} \sin\beta - k_{\mathrm{D}0} \cos\beta)\,\rho V^2 c \qquad . \quad . \quad . \quad (55)$$

which is positive when

$$k_{\mathrm{L}} \tan\beta - k_{\mathrm{D}0} > 0$$

or when

$$8a^2/h < m k_{\mathrm{L}} \qquad . \quad . \quad . \quad . \quad . \quad (56)$$

where, as before, $m = k_{\mathrm{L}}/k_{\mathrm{D}0}$.

(b) The Velocity Field of the Circular Vortex

Let r_1 and r_2 be the least and greatest distances respectively of a point P from the core of a circular vortex which has a circulation Γ (see Fig. 28). Then,

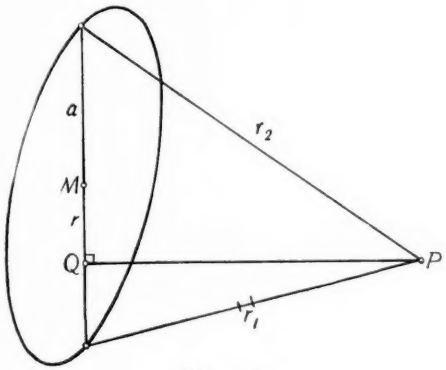

FIG. 28.

according to H. Lamb, the stream function for the flow (with Γ negative since the velocity inside the vortex is opposite in direction to that of the stream) is

$$\psi = (\Gamma/2\pi)\,(r_1 + r_2)\,\{\,K(k) - E(k)\,\} \qquad . \quad . \quad . \quad (57)$$

in which the modulus of the elliptic functions is

$$k = (r_2 - r_1)/(r_2 + r_1).$$

Taking P in the plane of the vortex, at the point Q at a distance r from the centre M of the vortex we find

$$r_2 = a + r, \quad r_1 = a - r.$$

With these values (57) becomes

$$\psi = (a\Gamma/\pi)\,\{\,K(r/a) - E(r/a)\,\} \qquad . \quad . \quad . \quad (58)$$

ψ has now been defined in such a way that the velocity component perpendicular to the plane of the vortex is given by $u = -(1/r)\,\partial\psi/\partial r$. In order to conform to the notation of Chapter II we write for this, $-u'$, so that $u' = (1/r)\,\partial\psi/\partial r$. Putting $r/a = k$ we have

$$u' = (\Gamma/\pi r)\,\{\,dK/dk - dE/dk\,\} = (\Gamma/\pi r)\,\{\,E/kk'^2 - E/k\,\} \,*$$

from which

$$u' = \{\,a\Gamma/(a^2 - r^2)\,\}\,E(r/a) \qquad . \quad . \quad . \quad . \quad (59)$$

For the velocity at the centre of the vortex, $r = 0$, $E = \pi/2$, we find

$$u'_{r=0} = \Gamma/2a.$$

* Compare E. T. Whittaker and G. N. Watson, Modern Analysis (Cambridge, 1920), p. 251. It should be remembered that $k'^2 = 1 - k^2$.

(c) The Mutual Interference between the Elements of the Townend Ring

To determine the velocity reduction according to (59) when the vortex is replaced by a Townend Ring, it is necessary to find the value of Γ. This depends upon the local velocity which in turn depends on the circulation round the different parts of the ring.

As is well known, a straight aerofoil may be represented by a system of straight vortices distributed along the section. We will therefore imagine the ring to be replaced by a system of circular vortices. We will first examine the field of one of these small vortices in the vicinity of the vortex itself, in order to determine the interference velocity caused by the circulation of the whole system.*

If r_1 and r_2 are the least and greatest distances of a point P from a circular vortex, then putting $\Gamma=2\pi$ for simplicity, the stream function is, from (57),

$$\psi=(r_1+r_2)\{K-E\},$$

in which the modulus of the elliptic functions is $k=(r_2-r_1)/(r_2+r_1)$. With the system of axes shown in Fig. 29, in which the origin is taken at the vortex, and the co-ordinates of P are ξ and η, we have:—

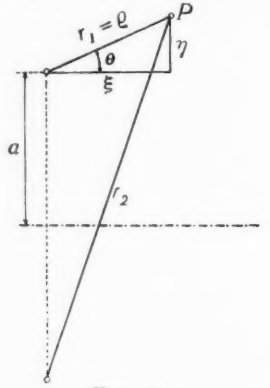

FIG. 29.

$$\left.\begin{aligned} r_1&=\sqrt{(\xi^2+\eta^2)}\\ r_2&=\sqrt{\{\xi^2+(2a+\eta)^2\}}\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (60)$$

If we write $\xi=\rho\cos\theta$, $\eta=\rho\sin\theta$, then

$$r_1=\rho,\ r_2=2a+\eta+\ldots=2a+\rho\sin\theta+\ldots,$$

and assuming that $\kappa=k'^2=1-k^2$, then,

$$\kappa=4r_2r_1/(r_2+r_1)^2=4(2a+\rho\sin\theta+\ldots)/\{2a+\rho(1+\sin\theta)\ldots\}^2$$

from which

$$\kappa=(2\rho/a)\{1-(\rho/a)(2+\sin\theta)/2\ldots\} \quad . \quad . \quad . \quad (61)$$

and

$$\log(16/\kappa)=\log(8a/\rho)+(\rho/a)(2+\sin\theta)/2+\ldots \quad . \quad . \quad (62)$$

Now

$$K=\tfrac{1}{2}\log(16/\kappa)+(\kappa/8)\{\log(16/\kappa)-2\}+\ldots$$
$$E=1+(\kappa/4)\{\log(16/\kappa)-1)\}+\ldots$$

from which

$$K-E=\tfrac{1}{2}\log(16/\kappa)-1-(\kappa/8)\log(16/\kappa)+\ldots$$
$$=\tfrac{1}{2}\log(8a/\rho)-1-(\rho/4a)\log(8a/\rho)+(\rho/a)(2+\sin\theta)/4+\ldots \quad . \quad (63)$$

* The derivation is due to Prof. J. M. Burgers, of Delft.

so that

$$\psi = 2a \{ 1 + (\rho/a)(1+\sin\theta)/2 + \ldots \} \{ \tfrac{1}{2}\log(8a/\rho) - 1 - (\rho/4a)\log(8a/\rho) + (\rho/a)(2+\sin\theta)/4 + \ldots \}$$
$$= a \{ \log(8a/\rho) - 2 + (\rho\sin\theta/2a)\log(8a/\rho) - \rho\sin\theta/2a \ldots \} \quad . \quad (64)$$

Expressed in terms of $\xi+\eta$, this is

$$\psi = a [\log \{ 8a/\sqrt{(\xi^2+\eta^2)} \} - 2 + (\eta/2a)\log \{ 8a/\sqrt{(\xi^2+\eta^2)} \} - \eta/2a] \quad (64a)$$

Since $u = -\{1/(a+\eta)\}(\partial\psi/\partial\eta)$ and $v = \{1/(a+\eta)\}(\partial\psi/\partial\xi)$, we find for the velocity components :—

$$u = -(1-\eta/a) \{ -\eta/(\xi^2+\eta^2) + (1/2a)\log [8a/\sqrt{(\xi^2+\eta^2)}] - \eta^2/2a(\xi^2+\eta^2) - 1/2a \}$$

or

$$u = \{ \eta/(\xi^2+\eta^2) \} - (1/2a)\log \{ 8a/\sqrt{(\xi^2+\eta^2)} \} + \xi^2/2a(\xi^2+\eta^2) \quad (65)$$

$$v = -(1-\eta/a) \{ 1+\eta/2a \} \{ \xi/(\xi^2+\eta^2) \} = -\xi/(\xi^2+\eta^2) + \xi\eta/2a(\xi^2+\eta^2) \quad . \quad . \quad . \quad . \quad . \quad (66)$$

Putting $\eta = 0$ we have

$$u = -(1/2a) \{ \log(8a/\xi) - 1 \} \quad . \quad . \quad . \quad (67)$$

and

$$v = -1/\xi \quad . \quad . \quad . \quad . \quad . \quad (68)$$

Comparing these values with those occurring with straight vortices, for which when $\eta = 0$, the values are $u = 0$ and $v = -1/\xi$, it is clear that there is only a difference in the axial component, of amount given by (67).

Now let $\gamma(x)\,dx$ be the strength of a small circular vortex at the position x of the vortex cylinder, then the velocity du_ξ in the point ξ due to the vortex ring is, from (67),

$$du_\xi = -(\gamma(x)\,dx/2\pi)(1/2a) \{ \log [8a/(\xi-x)] - 1 \}$$

Integrating over the whole vortex system,

$$u_\xi = -\int (\gamma(x)/4\pi a) [\log \{ 8a/(\xi-x) \} - 1]\,dx$$

where

$$\int \gamma(x)\,dx = \Gamma.$$

For the mean velocity near the section we may write

$$u_m \cong \int u_\xi \gamma(\xi)\,d\xi/\Gamma$$

which integral may be put in the form :—

$$u_m = -(\Gamma/4\pi a) \{ \log(8a/\delta c) - 1 \} \quad . \quad . \quad . \quad (69)$$

in which δ is approximately one-half for a symmetrical section, and probably somewhat less for a normal aerofoil section.

According to Lord Kelvin the velocity in the vicinity of a thick vortex ring of radius a and thickness b is

$$-(\Gamma/4\pi a) \{ \log(8a/b) - \tfrac{1}{4} \}$$

Writing the value given by (69) in the same form we get

$$u_m = -(\Gamma/4\pi a) \{ \log(8a/2.12\,\delta c) - \tfrac{1}{4} \}$$

or putting $2.12\,\delta = 1$ approximately

$$u_m \cong -(\Gamma/4\pi a) \{ \log(8a/c) - \tfrac{1}{4} \} \quad . \quad . \quad . \quad (69a)$$

If V_a is the velocity near the section of a Townend Ring in a stream of velocity V and $s = \log(8a/c) - \tfrac{1}{4}$ then from (69a) we may write

$$V_a = V - \Gamma s/4\pi a \quad . \quad . \quad . \quad . \quad . \quad (70)$$

and since $\Gamma/\Gamma_0 = V_a/V$ where Γ_0 is the circulation round the single straight aerofoil section in the same stream we find, after some reduction,

$$\Gamma = 4\pi a V\Gamma_0/(4\pi a V + s\Gamma_0) = \Gamma_0 \{ 1 - s\Gamma_0/(4\pi a V + s\Gamma_0) \} \quad . \quad . \quad (71)$$

From the foregoing it may be concluded:—

Conclusion V*a*.—The disturbance in the circulation round an element of a Townend Ring in a uniform stream due to the interference of the rest of the ring can be calculated by treating the ring as a thick circular vortex whose thickness is equal to the chord of the ring.

(d) The Velocity Field inside a Townend Ring

It was shown in Chapter II that for points further than one chord below an aerofoil the aerofoil may be replaced by a vortex. Similarly, in the case of the Townend Ring, for points within the ring at a radius of less than $a-c$ from the centre we may replace the ring by a circular vortex.

Over the range $o \leqq r \leqq a-c$ the velocity V_r at a point of radius r may be written, from (59),

$$V_r = V - \{ a/\pi (a^2 - r^2) \} E (r/a) \quad . \quad . \quad . \quad (72)$$

It follows easily from this formula that the velocity reduction is smallest at the centre and increases with r.

Equation (72) may be written, from (71), as

$$V_r = V - \{ aE\Gamma_o/\pi (a^2 - r^2) \} \{ 1 - s\Gamma_o/(4\pi aV + s\Gamma_o) \} \quad . \quad (72a)$$

Neglecting the small correction contained in the last factor, the velocity reduction is proportional to the circulation round the section.

By differentiating (72*a*) with respect to a, it will be seen that the velocity reduction decreases as the radius of the ring increases.

As shown in Chapter II, the velocity distribution in the range $a-c < r < a$ may be regarded as parabolic. To determine this distribution we notice that the parabola must pass through the points:—

$$\left.\begin{array}{l} r = a-c,\ V_r = V - \{ a\Gamma/\pi c\ (2a-c) \}\ E \{ (a-c)/a \} \\ r = a,\ V_r = V - s\Gamma/4\pi a - u_{po}\ (\Gamma/\Gamma_o) \end{array}\right\} \quad . \quad (73)$$

and that the tangent to the parabola at $r = a-c$ must be the same as the tangent at that point on the curve given by (72). The formula, though rather complicated in form, is obtained without great difficulty. It can, however, be seen immediately that in this range also the velocity reduction is approximately proportional to the circulation round the single aerofoil, while the obvious fact that here also the velocity reduction increases with r may be easily proved, for an arc-shaped section, for which the velocity at $r = a-c$ is larger than the velocity in points immediately below the section. For a section of arbitrary shape this cannot be proved immediately owing to the difficulty of expressing u_{po} in other units. Since, however, a normal aerofoil section behaves practically the same as a circular arc section, the foregoing conclusions may be applied directly to normal sections also. Finally, it follows from (72) and (73) that V_r, and therefore the velocity reduction is proportional to V, since Γ is proportional to V.

The following conclusions may now be stated:—

Conclusion VI*a*.—The velocity reduction inside a Townend Ring, for points more than one chord from the section, can be calculated by treating the ring as a circular vortex, and for points within one chord of the section, by assuming a parabolic distribution obtained from the velocity immediately beneath a single straight aerofoil, with a correction for the interference of the circular vortex.

Conclusion VII*a*.—The velocity reduction inside a Townend Ring is approximately proportional to the circulation round the section and to the velocity of the undisturbed stream; it is least at the centre and increases as the section is approached; it increases as the radius is reduced.

(e) The Influence of the Gauze Disc on the Townend Ring

As in the two-dimensional case we will now consider more exactly the interference of the gauze disc on the ring section. We will first obtain the interference flow in the plane of the ring, and then for simplicity find from it approximate expressions for the interference flow in front of and behind the ring.

Let dS (Fig. 30) be a surface element of the disc with co-ordinates r, ϕ. Let h be the radius of the gauze disc and a that of the ring. As previously, the element is considered as a source, whose strength, from (34a), is:—

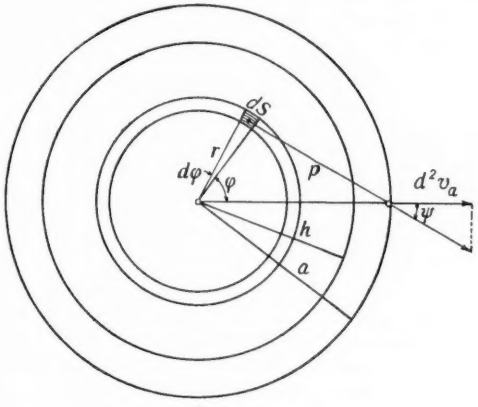

FIG. 30.

$$q = k_v V_r dS \quad . \quad . \quad . \quad . \quad . \quad (74)$$

The velocity perpendicular to the ring section due to the source is:—

$$d^2v_a = (q/4\pi p^2)\cos\psi$$

where

$$\cos\psi = (a - r\cos\phi)/p \text{ and } p^2 = r^2 + a^2 - 2ar\cos\phi$$

Since $dS = r \,.\, dr \,.\, d\phi$ the resultant interference velocity is

$$v_a = (k_v/4\pi) \int_0^h V_r r dr \left\{ \int_0^{2\pi} (a - r\cos\phi)\, d\phi/(r^2 + a^2 - 2ar\cos\phi)^{3/2} \right\} \quad . \quad (75)$$

In the velocity field inside a circular vortex of radius a and strength Γ, the velocity u' at a distance r from the centre is, according to Biot and Savart's equation (see Fig. 31):—

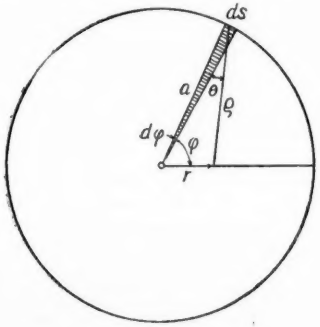

FIG. 31.

$$u' = \int_0^{2\pi} (\Gamma/4\pi\rho^2) \cos\theta \, . \, ds$$

in which $\rho^2 = a^2 + r^2 - 2ar\cos\phi$, and $\cos\theta = (a - r\cos\phi)/\rho$, so that, since $ds = ad\phi$

$$u' = (a\Gamma/4\pi) \int_0^{2\pi} \{ (a - r\cos\phi)\, d\phi / (a^2 + r^2 - 2ar\cos\phi)^{3/2} \} \quad . \quad . \quad (76)$$

Formula (75) now leads to

$$v_a = (k_v/a\Gamma) \int_0^h V_r u' r dr$$

Now $V_r = V - u'$, and the mean value $\Gamma_0/2a$ may be substituted for u' since u' is small compared with V and $\Gamma_0/2a$ is somewhat larger than the value $\Gamma/2a$ at the centre of the ring, the equations become

$$v_a = (k_v/a) \int_0^h (V - \Gamma_0/2a)\, u' r dr$$

for which we may write, from (58),

$$v_a = (k_v/\pi)\, (V - \Gamma_0/2a) \{ K(h/a) - E(h/a) \} \quad . \quad . \quad (77)$$

If we imagine this interference as due to a resistance at the centre of the ring, we may write, approximately, for the interference in front of or behind the ring section

$$v = (k_v/\pi) \{ a^2/(a^2 + 4b^2) \} (V - \Gamma_0/2a) \{ K(h/a) - E(h/a) \} \quad . \quad (78)$$

There will also be an interference velocity v' parallel to the stream. The mean value of this component over the chord of the section, when the gauze is midway between leading and trailing edges, is zero, from which it is evident that in the case of the Townend Ring the influence of the gauze is to change the angle of incidence of the ring section.

If β is the change in the angle of incidence then

$$\tan\beta = v/(V - s\Gamma/4\pi a)$$

Allowing for the fact that the value of v from (78) is somewhat too great, we may write

$$\tan\beta \cong (k_v/\pi) \{ a^2/(a^2 + 4b^2) \} (1 - \Gamma_0/2aV) \{ K(h/a) - E(h/a) \} \quad (79)$$

If α is the incidence for maximum circulation in the absence of the gauze disc, it will be seen that the section must be rotated so as to reduce this angle by the amount β to obtain maximum circulation with the disc present.

Properly speaking (79) only holds when $h < a - c$. Since, however, the formula yields somewhat too small a value when $a - c < h < a$ owing to the velocities near the edge of the gauze being higher than calculated, while on the other hand the factor $a^2/(a^2 + 4b^2)$ will certainly be too great, we may apply (79) as an approximation over the whole interval $0 < h < a$.

The conclusions which follow from the above are quite similar to Conclusions VIII and IX.

(f) The Drag of the Gauze Disc in the Presence of a Townend Ring

Let w_0 be the drag of the gauze disc, then

$$w_0 = \tfrac{1}{2}\pi h^2 k_L \rho V^2.$$

For the disc inside the Townend Ring we have

$$dw = \pi r dr k_L \rho\, (V - u')^2 \quad . \quad . \quad . \quad . \quad (80)$$

or

$$w = \pi k_L \rho \int_0^h (V - u')^2\, r dr$$

and since u' is small compared with V

$$w \cong \pi k_L \rho \int_o^h (V^2 - 2u'V)\, rdr$$

$$= w_o - (4w_o/Vh^2) \int_o^h u' r dr$$

which, from (58), gives

$$w = w_o - (4w_o/Vh^2)\,\psi = w_o \left[1 - 4a\Gamma/\pi h^2 V \left\{ K(h/a) - E(h/a) \right\} \right] \qquad (82)$$

Formulæ (81) and (82) give too small a value for the drag of a gauze disc whose radius is greater than $a-c$. If an accurate determination of the drag is required it is necessary to use the parabolic velocity distribution and integrate numerically. The factors which govern the velocity reduction are the same, however, in either case so that the following conclusions hold for every gauze disc :—

Conclusion X*a*.—Inside a Townend Ring a gauze disc undergoes a drag reduction approximately proportional to the circulation and inversely proportional to the velocity of the stream, but it increases considerably if the diameter of the ring is reduced.

Conclusion XI*a*.—The percentage reduction in drag is independent of the velocity of the uniform stream and the geometrical scale of the system.

(g) The Towing Force of the Townend Ring

For the towing force of the ring, neglecting the drag of the section itself, we may write approximately

$$T \cong 2\pi a \rho\, (V - s\Gamma/4\pi a)^2\, k_L c \tan \beta,$$

and since, from (79), $\tan \beta$ is proportional to k_v, and thus increases more rapidly than k_L, a conclusion similar to Conclusion XII can be drawn.

(h) The Relation between the Towing Force of the Ring and the Drag of the Gauze Disc

If the ratio of the towing force of the ring to the drag reduction of the gauze disc is compared with the similar ratio for the two aerofoils and gauze screen as given by equations (41), (42), (55) and (82), it will be seen that the ratios are approximately the same, as might be expected from Conclusions II and II*a*. From this, together with Conclusions XIII and XIV we also obtain :—

Conclusion XIII*a*.—The maximum drag reduction of a gauze disc inside a Townend Ring is approximately twice the product of the maximum lift, per unit length of the ring, the circumference of the ring and the sine of the angle of disturbance.

Conclusion XIV*a*.—Neglecting the drag of the ring section, the maximum drag reduction of the gauze disc when the ring is attached to it is approximately $1\frac{1}{2}$ times the maximum drag reduction of the screen when detached.

(i) The Relation between the Action of the Townend Ring and that of the Straight Aerofoils

Since the conclusions drawn for the ring agree closely with those previously obtained for the two-dimensional case, it follows that the circumstances of one case may be judged from those of the other. This is particularly so when comparisons are made in which certain factors are regarded as constants. For example, if a, h and c are held constant we find, from (41)

$$w = w_o\, (1 - c_1\Gamma/V + c_2\Gamma^2/V^2)$$

and from (82)

$$w = w_o\, (1 - c'_1\Gamma/V + c'_2\Gamma^2/V^2)$$

in which the c's are constants and c_2 and c'_2 are small compared to c_1 and c'_1 respectively.

This agreement between the two- and three-dimensional cases was also found by Townend experimentally. After certain measurements had shown that the lift coefficient of the section was an important factor he constructed a kind of two-dimensional engine body combination in order to obtain in a simple way some idea of the effect on drag reduction of such factors as diameter of the ring, and chord and incidence of the ring section. Townend makes the following remarks* about the agreement and the results obtained with this model:—

"This may appear a very crude and unlikely method of procedure, but as only *changes* in drag were required it was given a trial. Subsequently it was found that the results obtained, when applied to rings, were substantiated quite closely and gave a good idea of the relative importance of the different factors. Only in the value of the angle between the chord of the section and the axis was there a serious difference and this was due mainly to the difference in the streamline configuration of the flows in two and three dimensions."

From equations (38) and (79) it will be seen that in the case of the gauze screen also, there is a close relationship between the angles of disturbance in two and three dimensions. Thus we have respectively

$$\tan \beta = k_v (c_1 - c_2 \Gamma / V) \text{ and}$$
$$\tan \beta = k_v (c'_1 - c'_2 \Gamma / V)$$

in which c_1, c'_1, c_2 and c'_2 are constants which depend upon the dimensions and arrangement.

CONCLUSION XV.—The drag reduction of a gauze disc inside a Townend Ring and the towing force on that ring can be judged from the drag reduction of a gauze screen between two straight aerofoils and the towing forces on those aerofoils.

(j) The Relation between the Drag Reduction of a Radial Air-cooled Engine due to a Townend Ring and that of a Gauze Screen between Two Aerofoils

We will now enquire into the effect of replacing the homogeneous gauze screen by a radial air-cooled engine.†

In the first place we may note that, while there will be a reduction in drag of the engine and a towing force on the ring, the lack of uniformity in the distribution of resistance within the ring due to the cylinders, etc., will produce an interference flow which must necessarily vary at different points of the ring. This will cause an irregular distribution of circulation along the ring. A mean interference velocity must therefore be assumed, which will be that given by replacing the engine by a gauze disc of resistance equal to that of the engine.

The Townend Ring can then be designed so that the resultant angle of incidence as modified by the interference velocity shall be equal to that corresponding to maximum circulation round a straight aerofoil of similar section.

The variation in circulation along the ring will be equivalent to a variation of incidence about the angle at which maximum circulation is obtained with a gauze disc.

As in both cases the same relation exists between the circulation and the drag reduction it follows that the maximum drag reduction of a radial engine can be estimated from that of a gauze disc inside a Townend Ring when the angle of the section is varied.

The fact that when estimating the effect of a given ring the engine may be replaced by a gauze disc was noticed a long time ago by the Rijks Studiedienst

* Journal of the Royal Aeronautical Society, October, 1930, p. 820.
† In this Chapter, airscrew interference is presumed to be absent.

voor de Luchtvaart at Amsterdam. As a result in many of the tests undertaken by them this simplified method was used. In these tests the net effect of the drag reduction and the towing force was measured. For moderate variations in the circulation the ratio between the drag reduction of the gauze, and the towing force will not be altered. We thus obtain, in conjunction with Conclusion XV:—

Conclusion XVI.—The drag reduction of a radial air-cooled engine obtained with a Townend Ring may be judged from that obtained with gauze screen between two aerofoils.

(k) General Considerations regarding the Reduction of Drag of the Radial Engine *

Owing to the fact that the radial engine is thicker than a gauze disc, and also to the fact that the circulation varies along the circumference of the ring due to the variable cylinder interference which causes induced drag, the maximum drag reduction of the engine will always be less than that obtainable with a homogeneous gauze disc. From this would be expected that the greatest drag reduction will occur with engines which cause least variation of circulation round the ring, *i.e.*, with engines having many cylinders. Further, the drag reduction is greatest near to the ring, and on this account also the multi-cylinder engine will gain most advantage from the ring since a greater proportion of its bulk will lie in the region of greater drag reduction. This is substantiated by the results of Townend's experiments. In his paper to the Royal Aeronautical Society,† Townend says:—

"Tests made with different numbers of cylinders from three to nine showed that the percentage reduction in drag increased with number of cylinders up to nine cylinders.

"Tests on the two-dimensional model, with two rows of cylinders indicated that good results should be obtained with this type of engine also. Messrs. Armstrong, Whitworth Aircraft, Ltd., very kindly lent a one-fifth scale model of their Siskin aeroplane body with a 14-cylinder 'Jaguar' engine attached, and several rings were tested on this model with good results."

It may be of interest to mention here some experiments made by Townend in 1930 in which he measured the effect of a ring on the drag of an *impervious* disc. The accompanying table contains the results of these tests. They are plotted in Fig. 32, which also shows the relative position of ring and disc. The present theory does not, of course, cover the case of an impervious disc, but it will be seen that the drag of the disc alone is least when it is near the plane of the leading edge of the ring as predicted (for a gauze disc) in Chapter II, §(*h*) and observed in the experiments of Chapter III.

Forces on Impervious Disc when Surrounded by a Ring, but not attached to it.

Dimensions:—

Radius of trailing edge	3·56″
Chord	2·0″
Angle	−5°
Diameter of disc	5″

Distance of disc behind leading edge of ring, x (ins.).

Speed of tests, 60 ft./sec.

Drag of disc alone, 0.678lbs. $= R_0$.

* The remarks in this paragraph relate, strictly, to engines not mounted in a body, but the argument is probably applicable to engine-body combinations also.

† loc. cit.

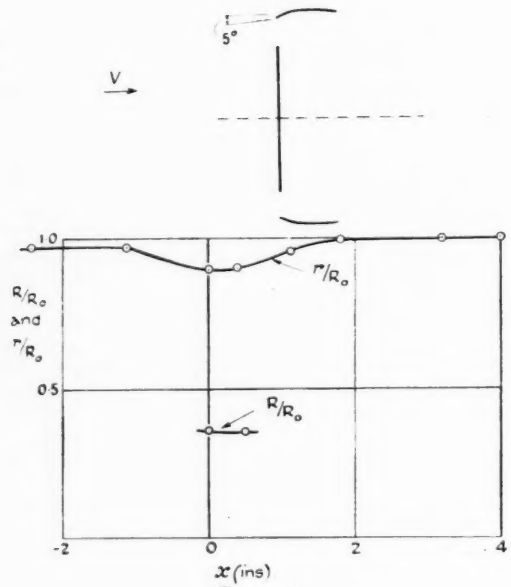

FIG. 32.

DRAG OF IMPERVIOUS DISC IN THE PRESENCE OF THE RING (=r).

x (ins.)	Drag, r (lbs.)	r/R_0
−2.4	0.660	0.974
−1.1	0.660	0.974
0.0	0.610	0.900
0.4	0.612	0.903
1.1	0.650	0.959
1.8	0.676	0.997
3.2	0.678	1.000
4.0	0.684	1.008

DRAG OF IMPERVIOUS DISC WITH RING ATTACHED (=R).

x	Drag R.	R/R_0
0	0.244	0.360
0.5	0.241	0.355

(l) Conditions which a Good Townend Ring must Satisfy

The theory presented in this paper suggests that the following conditions should be fulfilled:—

1. The lift coefficient of the section should be as high as possible, and on account of the variation in incidence caused by the cylinders the lift curve should be as flat as possible near its maximum. From a comparison of the formulæ for drag and towing force it is clear that, in agreement with Townend's conclusion, a high lift coefficient is much more important than a low drag coefficient. This suggests that even better results might be obtained by using a singly- or multi-slotted section.

2. The circulation is directly proportional to the chord (though the more remote parts of the ring will contribute less to the drag reduction); as the chord

is increased the drag of the section increases as the first power and the induced drag as the square of the chord while the angle of interference decreases. This leads to a limit to the chord length, which can, however, only be found empirically, since it depends chiefly on the shape and dimensions of the engine and particularly of the body, etc. Townend says,* in speaking of the body-engine combinations which he tested:—

"The reduction in drag increases steadily with increase of chord up to 12ins. or 14ins. (full-scale) and then more slowly. The further improvement in going to 16ins. is slight—of the order of 2 or 3 per cent. of R_0 (the drag without ring). At the same time, in these tests the chord was not increased to the point where it was actually a disadvantage, except in one solitary case in two dimensions, in which a chord corresponding to about 18ins. (full-scale) was tested and appeared to be too great. It cannot, therefore, be considered proved that a larger chord would always be detrimental although it may be presumed that from most practical points of view the smaller the chord the better."

We can only add that with a multi-cylinder engine the chord can be made somewhat larger than with an engine with few cylinders.

3. Regarding velocities due to the thickness of the ring section, the advantage will lie with the thin sections, as found by Townend† also, though the direct effects of the lift and drag coefficients in his tests are not known.

4. The diameter of the ring should be as small as possible. Townend‡ writes about this as follows:—

"The radial situation should be such that the diameter of the trailing edge is not greater than that of the engine. It is probable that the best results will be obtained when the rear edge of the ring is cut away to fit round the valve rockers, but if this is done the rocker hats should be faired into the upper surface. It may be preferable to permit small projections of properly faired than to increase the size of the ring so as to surround everything."

It is clear from the above how important Townend thought it was to keep the diameter as small as possible—in agreement with our theory—though we do not share the view that the diameter should be so small as to allow the valve rocker to project through the ring. Such an arrangement would interfere appreciably with the circulation, which is virtually the only factor of any account in the ring's action, and would produce extra induced drag.

5. The choice of correct angle of the ring section is one of prime importance, since the circulation, and therefore the drag reduction, depend directly upon it. When the ring section stalls the circulation decreases greatly, and the consequent increase of engine drag tends to increase the stall further. The angle must therefore be such that the highest possible average circulation is obtained without the section stalling seriously at any point. From this it follows that the incidence of the section, as found approximately by decreasing the angle of maximum lift of the infinite aerofoil by the angle of interference calculated when the engine is replaced by a gauze disc of the same diameter, has in practice to be modified somewhat. The results of Townend's experiments§ may be quoted in this connection:—

"It is not possible to give a definite value for the best angle of the chord line or the no-lift line to the body axis, as it will depend to some extent on the shape of the nose. It should, however, be fairly flat, that is, at such an angle to the *local* wind stream that the section shall be working at a fairly high lift, though not high enough to risk stalling. In most cases the no-lift line of the section should be inclined at 3° or 4° to the body axis, such that, if produced, it would intersect that axis in front of the nose."

* loc. cit.
† loc. cit. (Journal, p. 825).
‡ loc. cit. (Journal, p. 828).
§ loc. cit. (Journal, p. 828).

(m) Generality of the Townend Ring Principle

From what has been said above, it follows at once that from a physical point of view, the radial engine plays a relatively unimportant part in the aerodynamics of the Townend Ring, of which it is only one special application. The circular shape, when applied to a circular body such as a gauze disc, is theoretically better than any other, *e.g.*, a polygonal one, since in the latter case induced drag will result from interference of the parts. This is probably unimportant when the body is itself star shaped, like a radial engine. Townend himself obtained very good results with polygonal " rings " attached to radial engines, and it is also obvious that a larger drag reduction would be obtained on, say, a square shaped radiator, by means of an aerofoil arranged closely around it instead of as a ring.

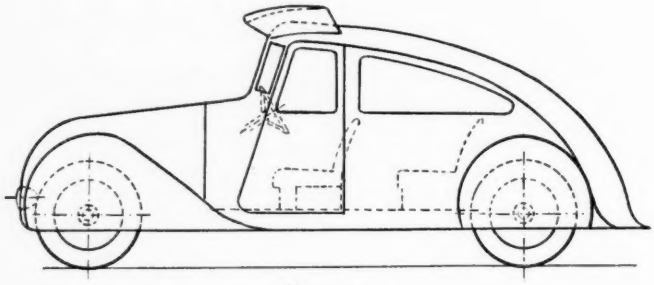

FIG. 33.

Fig. 33 illustrates an example of the possibility of reducing the air resistance of a motor car by means of an aerofoil. This and other applications are also mentioned by Townend in R. & M. 1267 and in the Journal of the Royal Aeronautical Society.

CHAPTER V.

THE POSSIBLE INFLUENCE OF TURBULENCE IN THE FLOW ON THE ACTION OF THE TOWNEND RING

The Townend Ring does not always yield in flight such good results as are to be expected from small scale model tests made without an airscrew. In their paper, " Some Experiments on Nacelles with Townend Rings,"* C. Koning and H. J. van der Maas suggest the following causes for this reduced effectiveness of the ring :—

(*a*) A change in airscrew characteristics produced by the ring.

(*b*) The change in incidence of the ring section due to contraction of the slipstream.

(*c*) The influence of rotation and turbulence in the slipstream on the action of the ring.

They suggest as a result of these experiments that (*c*) is of chief importance. It should be remembered, however, that these experiments are on a small scale and on this account the influence of turbulence would be expected to be greater than if large models had been used.

In considering the subject of slipstream turbulence in the light of our previous work we may note :—

* Fifth Congres Internationale de l'Aviation (The Hague, 1930), pp. 568 and 573.

(1) That as the variations in incidence increase, due to increasing turbulence, the mean circulation along the ring will decrease.

(2) As the irregularity of the distribution of the circulation along the ring increases, due to increasing turbulence, (i) a larger induced drag will be produced, and (ii) an increase in the strength of the horse-shoe vortices shed by the ring* will result, giving a higher engine drag.

Of the above (1) has been dealt with in Chapter IV, and we will now consider (2) more closely.

(b) The Induced Drag of the Ring due to Irregular Distribution of Circulation along it

In addition to irregularity in the distribution of circulation due to turbulence and rotation in the slipstream there is a further irregularity due to the fact that the radial engine is not a surface of revolution. A formula which takes account of all the factors is not obtainable, but to get some idea of the induced drag due to irregularities of distribution we will take as a very simple case the distribution which is expressed by the formula:—

$$\Gamma=\Gamma_1+\Gamma_2\cos n\phi \quad . \quad . \quad . \quad . \quad . \quad (83)$$

We will then apply the theorem from aerofoil theory that when, at the point $s_1\Gamma$ increases by $d\Gamma=(d\Gamma/ds)\,ds$ over a distance ds along the ring, a vortex element of strength $d\Gamma$ springs from the ring and goes downstream. If $d\Gamma$ is positive when ds is positive then the direction of rotation in the vortex is such that it produces, at the ring, a radial velocity directed inwards or outwards according as $s>$ or $<s_1$.

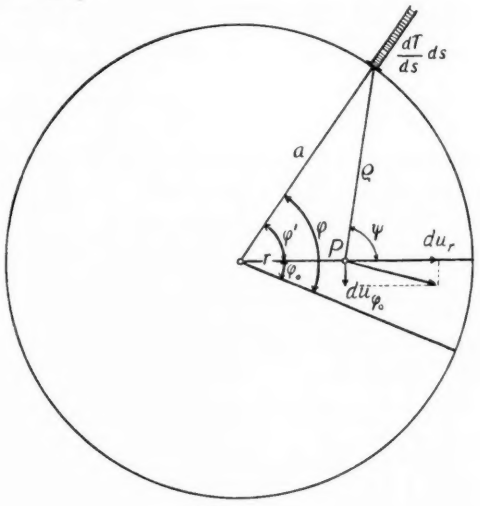

FIG. 34.

In Fig. 34 P is a point inside the ring and in its plane and has the co-ordinates r and ϕ_0. The velocity components du_r and du_{φ_0} at P due to the vortex $(d\Gamma/ds)\,ds$, whose axis is normal to the plane of the paper, are

$$du_r=(\sin\psi/4\pi\rho)\,(d\Gamma/ds)\,ds \text{ and } du_{\varphi_0}=-(\cos\psi/4\pi\rho)\,(d\Gamma/ds)\,ds$$

* See H. Glauert, M.A., "The Elements of Aerofoil and Airscrew Theory," Cambridge, 1930, p. 162. Here the horseshoe vortices are bent.

where ρ is the distance from P to the element and ψ its direction relative to a diameter through P. We then have

$$\rho \sin \psi = a \sin (\phi - \phi_0), \quad \rho \cos \psi = a \cos (\phi - \phi_0) - r$$
$$\text{and } \rho^2 = a^2 + r^2 - 2ar \cos (\phi - \phi_0),$$

while (83) gives

$$(d\Gamma/ds)\, ds = -n\Gamma_2 \sin n\phi d\phi.$$

Inserting these values in the previous equations and integrating we have

$$\left.\begin{aligned} u_r &= -(na\Gamma_2/4\pi) \int_0^{2\pi} [\sin (\phi - \phi_0) \sin n\phi / \{ a^2 + r^2 - 2ar \cos (\phi - \phi_0) \}]\, d\phi \\ \text{and} \\ u_{r0} &= +(n\Gamma_2/4\pi) \int_0^{2\pi} [\{ a \cos (\phi - \phi_0) - r \} \sin n\phi / \{ a^2 + r^2 - 2ar \cos (\phi - \phi_0) \}]\, d\phi \end{aligned}\right\} \quad (84)$$

To find the induced drag we only need the velocity immediately beneath the section, so that in (84) we may write $r = a$. It is then evident that $u_{r0} = 0$ while

$$(u_r)_{r=a} = u_a = -(n\Gamma_2/8\pi a) \int_0^{2\pi} \{ \sin (\phi - \phi_0) \sin n\phi / [1 - \cos (\phi - \phi_0)] \}\, d\phi \quad (85)$$

or writing $\phi - \phi_0 = \phi'$

$$u_a = -(n\Gamma_2 \cos n\phi_0 / 8\pi a) \int_0^{2\pi} \{ \sin \phi' \sin n\phi' / (1 - \cos \phi') \}\, d\phi'$$
$$-(n\Gamma_2 \sin n\phi_0 / 8\pi a) \int_0^{2\pi} \{ \sin \phi' \cos n\phi' / (1 - \cos \phi') \}\, d\phi'$$

The last integral is zero since it only changes sign when $2\pi - \phi'$ is written for ϕ'.

The first integral may be written

$$I = 2 \int_0^{\pi} \{ \sin \phi' \sin n\phi' / (1 - \cos \phi') \}\, d\phi', \text{ and putting } \phi' = 2\theta$$
$$I = 2 \int_0^{\pi/2} \{ 2 \sin \theta \sin 2n\theta / (1 - \cos 2\theta) \}\, d\theta = 2 \int_0^{\pi/2} \{ 2 \cos \theta \sin 2n\theta / \sin \theta \}\, d\theta$$
$$= 2 \int_0^{\pi/2} \{ [\sin (2n+1)\theta - \sin (2n-1)\theta] / \sin \theta \}\, d\theta = 2\pi$$

so that

$$u_a = -(n\Gamma_2/4a) \cos n\phi_0 \quad . \quad . \quad . \quad . \quad . \quad (86)$$

Since with a positive circulation a velocity towards the centre of the ring causes a positive induced drag, the share of an element ds_0 of the ring in this drag is

$$dW_i = -L_a (u_a / V_a)\, ds_0$$

where L_a is the lift per unit length and V_a the velocity at the element ds_0.

From Joukowski's equation and equations (83) and (86) we find, since $ds_0 = a d\phi_0$

$$dW_i = (\rho n \Gamma_2/4)(\Gamma_1 + \Gamma_2 \cos n\phi_0) \cos n\phi_0 d\phi_0$$

which gives, on integration,

$$W_i = (\pi\rho/4)\, n\Gamma_2^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (87)$$

Equation (87) shows that an induced drag on the ring can be created which may become large for large values of $n\Gamma_2^2$. Here n represents the number of fluctuations in the circulation along the circumference of the ring, while Γ_2 is their amplitude. The two factors are not independent since with a large number of fluctuations the amplitude will be small. From (87) it appears that in the case considered the amplitude will have the greater influence.

It is probable that the distribution of circulation around a ring surrounding a radial engine will be somewhat similar to the case considered above. It is also probable that turbulence in the slipstream of the airscrew may cause fluctua-

tions in the circulation sufficient to produce appreciable induced drag. The drag reduction obtainable in practice may therefore be diminished somewhat on this account, though it is impossible to calculate the net result of these various effects theoretically. Moreover, they may be complicated by possible instability in the flow. It is probable, however, that the induced drag will be smaller with many cylinders than with few.

(c) The Effects of the Horse-shoe Vortices on the Drag. Experiments with a Turbulent Airstream

It may be surmised that the velocities in the plane of the ring, as given by (84), will give rise to increased drag, specially as they are fluctuating due to the presence of the airscrew, but it is difficult either theoretically or experimentally to obtain an idea of this increase. Some extra tests, however, have been made on the possible effects of turbulence in the stream on the drag reduction and these are described below. Two groups of tests, extending those given in Chapter III, were made on the gauze screen between two aerofoils, in which a turbulence producing network was introduced upstream. The drag of the screen was measured as a function of aerofoil incidence both with and without the network. The screen was 8.5 mm. behind the leading edges of the aerofoils, which were 112 mm. apart. Two networks were used, both of which filled the tunnel. The first was a simple piece of wire netting made of 0.5 mm. wire at 3.4 mm. pitch nailed to a wooden frame having an edge width of 48 mm. It was placed 270 mm. in front of the screen. The second network was made of lathes 20 mm. in width and 60 mm. apart, inclined at 45° with the span of the aerofoils. This network was placed 37 mm. in front of the gauze screen. Thus the first network produced small scale turbulence and the second a coarse degree of turbulence.

In both groups of tests the force L^* normal to the tunnel axis was measured on one aerofoil. With the lath network one test was repeated with the lathes turned through 90° and the average of the two positions taken.

The tunnel speeds in front of the networks were 19.59 and 18.76 m./sec. for the wire and lath networks respectively.

The results of the drag measurements are given in Figs. 35 and 36 together with the lift coefficient $k_L{}^*$, determined from measurements of L^*. In Fig. 35

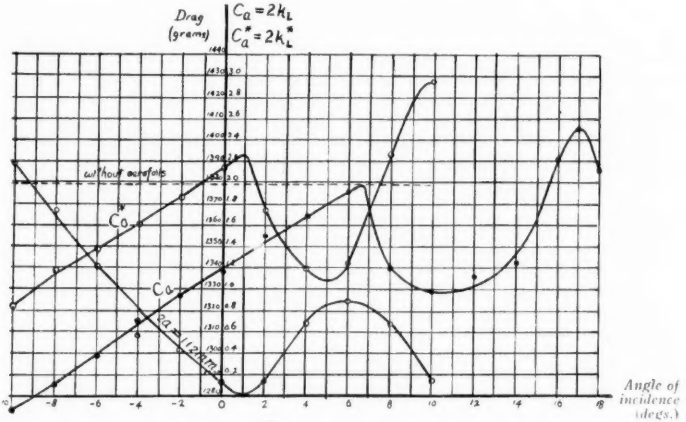

FIG. 35.

Drag of gauze screen and coefficients k'_L and $k_L{}^*$ behind wire network.

the high value of k_L^* is conspicuous, and to account for this further tests were made of the lift of a single section, and of the velocity, behind the wire network. The lift results have also been plotted in Fig. 35 as values of k'_L. Bearing in mind what was said about the corresponding tests without artificial turbulence, and the fact that a prevailing induced drag will slightly increase k_L^*, the values of k'_L and k_L^* do not show any remarkable disagreement, the values of k'_L being high also.

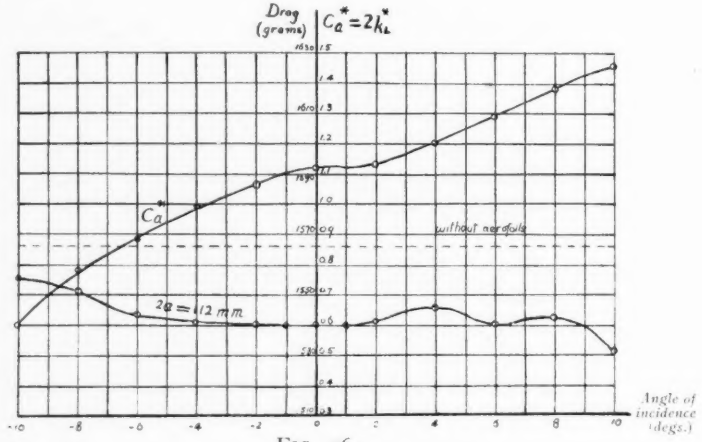

FIG. 36.

Drag of gauze screen and values of coefficient k_L^* behind the lath network.

On measuring velocities the aerofoil was found to have been influenced by the disturbance caused by the wooden edge of the network. At a velocity head of 22 kg./m.^{2} in the undisturbed stream, the following values of the velocity head were found at distances of 0, 100, 200 and 300 mm. from the tunnel axis: 45.45, 44.18, 46.70 and 43.50 kg./m.^{2}, whereas at 395 mm. from the axis, it appeared to be negative. Assuming the average of the above values (44.96) the ratio between the undisturbed velocity and that near the wake of the frame was

$$1 : 44.96/22.$$

From continuity of flow in the tunnel (section 800 × 800 mm.) the width of the disturbed flow can be assumed as $800\,(22/44.96) = 669$ mm.

The lift coefficient measured for the single aerofoil in the stream with " fine " turbulence was 0.97 for the first maximum and 1.25 for the second, both based on the velocity in the undisturbed stream and a span of 792 mm. Based on the calculated velocity and the effective part of the aerofoil span we find for the real k_L $0.97 \times (22 \times 792/44.96 \times 0.669) = 0.562$ for the first maximum and similarly 0.722 for the second. Since the lift coefficient of many aerofoils is known to increase with turbulence, the above values may be regarded as acceptable.

The results with the wire network show a decrease in drag with increasing lift coefficient of the same character as that obtained without artificial turbulence, but with the lath network the difference was more marked. Without turbulence a drag reduction of 15 per cent. was measured; with the wire network the reduction was 7 per cent., while with the lath network it fell to 2 per cent., which supports the view that turbulence affects the drag reduction adversely.

Applying this result to the radial engines with Townend Ring it is concluded that the turbulence due to rotation in the slipstream may reduce the reduction in drag obtainable, while, as already mentioned, an induced drag on the ring will tend to reduce the towing force on it.

We may therefore conclude that the drag reduction obtainable with a Townend Ring will generally be somewhat smaller under flying conditions than it would if no airscrew were present. There is no doubt that other factors, not taken account of, also have their effect.

ABSTRACTS OF PATENT SPECIFICATIONS

(Specially abstracted for the Journal by W. O. Manning, F.R.Ae.S.)

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Aerodromes

413,773. *Improvements in and relating to Elevated Centrally Pivoted Rotating Aerodromes or Airport Landing Grounds.* Frobisher, C., 8, The Crescent, Swaffham, Norfolk. Dated Feb. 7th, 1933. No. 3,674.

This specification describes an aerodrome where there is only one runway for aircraft but where this runway is arranged to rotate horizontally so that it can be moved into the appropriate position, according to the wind, to enable aircraft to land on it. It is suggested that the size of such a runway should be not less than 2,000 feet long and 300 feet broad. The rotating runway can be mounted on one tower, the extremities being supported as cantilevers, or a number of towers arranged in a ring may be used. The towers may be used as offices, etc. Methods of driving and braking the runway are described, and also methods of indicating to approaching aircraft the direction in which to land, it being understood that the direction of the runway is the same for winds differing 180 degrees in direction. The rotating runway may be arranged at differing heights above the ground according to local conditions, and various constructions appropriate to these different conditions are described.

Aerofoils

416,715. *Aircraft.* Zap Development Corporation, 230, Park Avenue, City and State of New York, U.S.A. Convention date (U.S.A.), Jan. 19th, 1932.

This specification refers to a method of increasing the lift of aerofoils by operating a flap attached to the underside and rear of the section; the flap, when operated, taking up an angle to the section, and, at the same time, moving back. It is proposed to connect a rod between the flap and the rear of the aerofoil so that when the flap is moved back by suitable mechanism this rod tends to take

up a vertical position thereby pushing down the rear of the flap. One type of mechanism is proposed in which rack and pinion gears are utilised for the purpose, the pinions operating upon threaded rods which carry nuts attached to the flap.

Aeroplanes—Construction

413,410. *An Improved Method and Means for Inserting and Positioning Distance Pieces in Tubular Structures.* Parnall, G. G., and Clarke, H. V., both of Coliseum Works, Park Row, Bristol. Dated Feb. 14th, 1933. No. 4,468.

In cases where bolts or rivets are used to secure parts to tubular members it is necessary to provide a distance piece between the opposite sides of the tube to prevent the latter dilating. In this case it is proposed to employ a split tubular distance piece which is introduced into the tube and then expanded by a taper tool. Claims are made for the general method and also for the special tool used.

412,717. *Improvements in and relating to Cockpit Wind-Shields, particularly for Aircraft.* Petters, Ltd., Bruce, R. A., and Davenport, A., all of Westland Aircraft Works, Yeovil, Somerset. Dated March 24th, 1933. No. 8,981.

It is proposed to provide, in addition to the pilot's windscreen, an additional windscreen behind the pilot to protect the occupant of the rear cockpit. This rear windscreen is arranged to enclose a sector arrangement of hood which can be closed rearward and which, when closed, encloses the rear occupant completely. Between the pilot's windscreen and the rear windscreen a slideable hood is fitted to enclose this space so that when both these hoods are closed both occupants are completely enclosed. The arrangement is shown arranged for the use of a rear gunner in a military aircraft, and it is pointed out that the latter is protected even when the rear cover is opened to enable him to use his gun. Arrangements are made for each of the occupants to leave the machine quickly when necessary.

416,543. *Improvements in or relating to Folding Wing Aeroplanes.* Baynes, L. E., of E. D. Abbott, Ltd., Farnham, Surrey, Dated Dec. 22nd, 1933. No. 36,111.

It is proposed to fold the wings of a high wing cantilever monoplane by swivelling the whole wing round a point adjacent to the rear spar so that it lies as near as possible to the centre line of the fuselage. Quick-release joints are provided in two places on the front spar, and provision is made for folding a cabin top out of the way when the wing is folded. Application of this method of folding to a twin-engined machine is described, and there are claims concerned with the design of the quick-release devices.

Aeroplanes—General

413,948. *Improvements in Auxiliary Lifting Means for Aeroplanes.* Wood, W. H., 248, Winona Drive, Toronto, Canada. Dated Dec. 6th, 1933. No. 34,266.

It is proposed to assist an aeroplane in rising by providing means intended to reduce the air pressure over the upper portion of the fuselage. The fuselage is provided with slots in its upper surface through which air is drawn by a fan operated by the engine or by other means. A member resembling a paddle-wheel is mounted on each side of the fuselage, the upper half of which is housed so that the lower half only is exposed to the air. These are described as stabilisers.

410,489. *Improvements in or connected with Flotation Gear for Aircraft.* Dagnall, R. F., 17, Stoke Road, Guildford, Surrey. Dated Nov. 16th, 1932. No. 32,389.

This invention provides means by which flotation gear for aircraft is automatically inflated when the aircraft touches the water. The lower forward part of the machine is provided with two spaced plates which are electrically connected by water, especially sea water, and allow a current to flow which operates the apparatus. These spaced plates can be duplicated as necessary, being connected in parallel. It is preferred to use liquid carbon dioxide for inflating the flotation gear, and this gas is carried in metal bottles which are sealed by a light breakable disc. This disc is arranged to be broken by the blow of a plunger, operated by a piston propelled by a cartridge which is, in its turn, fired by the current passed by the spaced plates. Manual operation is provided for in the event of failure of the automatic arrangements, and alternative methods of automatically generating gas are described.

Aeroplanes—Undercarriages

412,734. *Air Improved Differential Braking Device, Particularly Suitable for Wheels of Aeroplanes and other Vehicles.* (Madame) Y. L. Messier, 179, Boulevard Brune, Paris, France. Convention date (France), April 19th, 1932.

This specification refers to hydraulically-operated wheel brakes for aircraft in which arrangements are made for differentially operating the brakes on the wheels on either side of the machine. Reference is made to the British Patent 341,007, August 10th, 1928. The pressure for operating the brakes may be derived from a manually-operated pump and passes to a valve box. This valve box contains an arrangement by which valves are opened so that the pressure is first passed to the wheels equally. On the pressure being increased, a further valve is opened, the others being closed. This operation automatically allows the pressure to pass to the differential apparatus. This latter consists of a piston and cylinder, which piston carries a connecting rod which can be moved over a link connecting the pistons of two other cylinders which are connected to the wheels on each side of the aircraft. By sliding the connecting rod over the link, differential pressure is produced in the two cylinders and, therefore, in the wheels connected with them.

412,593. *Improvements relating to the Undercarriages of Aircraft.* The Comper Aircraft Co., Ltd., Heston Airport, Hounslow, Middlesex, and Flt. Lieut. N. Comper of the same address. Dated Dec. 29th, 1932. No. 36,815.

This undercarriage is of the retractable form in which each wheel is carried in a separate frame, there being a vertical post containing shock-absorbing devices on each side of the wheel and a triangular framework to the rear. The whole of this framework pivots on a point above the wheel and can be turned rearward about this point, so enabling it to be retracted into the wheel. A locking device is provided at the rear of the triangular framework and the wheel is allowed to project slightly in the retracted position so that the machine can land with the wheels retracted. Indicating devices are referred to for the purpose of reminding the pilot of the position of the wheels.

412,038. *Improvements in or relating to Landing Gear for Aircraft.* Clark, M. C., 53 and 54, Chancery Lane, London, W.C.2. Dated June 12th, 1933. No. 16,766.

This specification describes an amphibian gear for aircraft in which the wheels are in the floats. The floats may be pivoted forward so that they may be moved upwards to expose the wheel for alighting on land, or locked in a

fixed position for alighting on water. The floats may be so arranged that they are unlocked automatically for alighting on land, or it can be arranged that the wheels float upwards into the float when alighting on water; or these movements may be operated manually. An anchor, roughly of the mushroom type, is fitted to the nose of the floats so that their shape coincides with the curve of the floats. This is helped by the anchors being provided with rubber bumpers, which latter prevent accidental damage. Sprung rudders containing wheels are fitted to each float. The floats are fitted with water channels to reduce the water resistance of the wheel wells, and special strips forming skates are fitted for ice landings.

415,097. *Improvements in or relating to Brakes for Aircraft Wheels.* The India Rubber, Gutta Percha and Telegraph Works Co., Ltd., Aldwych House, Aldwych, London, W.C.2, and Tarris, F. J., of the above Company's Works at Silvertown, London, E.16. Dated Feb. 15th, 1933, No. 4,692; April 11th, 1933, No. 10,785; and Oct. 24th, 1933, No. 29,486.

The mechanism described is concerned with an arrangement for operating differentially fluid-operated brakes on the wheels on the opposite sides of aircraft. The main braking device which operates the brakes on the wheels to the same extent is controlled by the pilot, but the differential braking occurs only after the pilot has operated his control. This differential braking is effected by two members on opposite sides of the rudder bar which are operated by the rudder bar and which release the pressure, and therefore also the braking effect, from the appropriate wheel. In one form of the mechanism a system of toggle linkage is introduced operated by fluid pressure which prevents the differential braking from coming into operation on the ground until the rudder bar is centralised. Valves of the Schrader type, controlled by springs, operated by pistons, are used for the control of the fluid.

412,876. *An Improved Hydraulic Apparatus for Controlling Brakes.* (Madame) Y. L. Messier, 179, Boulevard Brune, Paris, France. Convention date (France), Feb. 4th, 1933.

This specification refers to aircraft wheel brakes operated by hydraulic means, *i.e.*, by oil under pressure. It is proposed to provide a piston operating in a cylinder and connected to the tail skid of the aircraft, so that the loads produced on the tail skid on landing operate the piston and produce a hydraulic pressure which operates the brakes. Arrangements are made for an over-riding control by the pilot for the brakes to be released when the skid leaves the ground, so as to prevent the machine turning over, and for a shock-absorbing device connected to the tail skid.

416,440. *Improvements in Aircraft Brakes.* The Dunlop Rubber Co., Ltd., 32, Osnaburg Street, London. Goodyear, E. F., Wright, J., and Trevaskis, H. W., of the Company's Works, Foleshill, Coventry. Dated May 10th, 1933. No. 13,564.

This specification describes a system of hydraulic brakes for aircraft in which equal or differential braking may be obtained, and in which provision is made against excess pressures. There is a central chamber filled with oil, from which project angularly two cylinders containing pistons. The rods for these pistons are connected to a triangular frame at one end, and at the other they are connected to the pistons by a ball head, which is used to seal an aperture in the piston through which fluid may pass. The pistons are kept in contact with the rods by springs, except at the lower end of the travel when the motion of the pistons is limited by a stop. The outer end of the pistons is connected to the brakes. The whole chamber, as well as the pistons, is full of oil, and pressure

is produced in it by means of a pump or by other suitable means. Differential braking is produced by moving the triangular frame which is connected to the rudder bar.

Airscrews

413,237. *Improvements in or relating to Land Planes.* Dornier-Metallbauten G.M.B.H. and Dr. Ing. C. Dornier, both of Friedrichshafen, Lake Constance, Germany. Convention date (Germany), March 4th, 1933.

In the case of aeroplanes fitted with two or more propellers mounted either on or in front of the leading edge of the wing it is proposed to arrange that the engine and propeller pivots on a horizontal axis so that the propeller can be raised in relation to the ground when taking off and returned to the normal position when the aeroplane is in flight. It is claimed that this arrangement enables a much lower chassis to be used than is normally possible, which facilitates the design of a folding chassis. The arrangement for pivoting the engine and the mechanism for folding the chassis can be combined, so that one operation effects both.

413,993. *Improvements in or relating to Land Planes.* Dornier-Metallbauten G.M.B.H. and Dr. Ing. C. Dornier, both of Friedrichshafen, Lake Constance, Germany. Convention date (Germany), March 11th, 1933.

It is proposed, that in the case of an aeroplane with its motor fitted in the front end of the fuselage, that provision be made to permit the propeller, with or without the motor, to be tilted upwards for the purpose of enabling the height of the landing chassis to be reduced. When the aeroplane is in flight the propeller is moved into the normal position with the motor shaft horizontal, and the mechanism enabling this to be done can be interconnected with that controlling a folding chassis, so that the chassis is folded when the propeller axis is horizontal, and the chassis is protruded when the propeller axis is tilted upwards.

415,622. *Improvements in Propelling Mechanism for Aircraft.* Ludwig Netter, 262, Ringstrasse-Otterstadt, near Speyer on the Rhine, Germany. Convention date (Germany), Dec. 12th, 1932.

The propeller described is of the paddle-wheel type. The radius arm is provided at its extremities with shafts carrying blades, which shafts are mounted at 90° to each other. The blade is mounted preferably at an angle of 45° to the blade shaft. The blade shafts are rotated by means of a bevel gear at the speed of rotation of the whole propeller, and the result is a feathering action which provides the desired propulsion. An arrangement of mechanism is described by means of which the pilot can advance or retard the piston of the maximum propelling action of the blades.

416,139. *Improvements in Gearing for Propellers.* Rowledge, A. J., Ellerolia, Trowels Lane, Littleover, Derby, England. Dated May 18th, 1933. No. 14,410.

This specification describes a mechanism for enabling an engine to drive two co-axially mounted propellers in opposite directions. One propeller shaft is driven directly by a gear wheel on the engine shaft gearing direct with a gear wheel on the propeller shaft. The other propeller shaft, which is mounted inside the first, is driven by a second gear wheel on the engine shaft which is connected to the gear wheel on the second propeller shaft by means of two pinions gearing with each gear wheel. The gears are arranged so that the propeller speeds can be reduced if desired and so that the speeds of the two propellers may be equal.

Armament

414,287. *Improvements in Means for Mounting Guns on Aircraft.* Birkigt, M., Rue de Capitaine Guynemer, Bois-Colombus (Seine), France. Convention date (France), April 15th, 1933.

This specification refers to gun arrangements in aircraft in which the gun is mounted on the engine so as to fire through the hollow propeller shaft; such propeller shaft being mounted in a line between the cylinders and driven by a gear. It is proposed to prevent the loss of oil from the point where the gun enters the propeller shaft by providing helical grooves in one of the elements concerned, so that the oil is forced back into the casing. A packing piece of rubber or other suitable material may also be employed.

414,300. *Improvements in Means for Mounting Guns on Aircraft Engines.* Birkigt, M., Rue de Capitaine Guynemer, Bois-Colombus (Seine), France. Convention date (France), Dec. 2nd, 1933.

In the case of guns arranged to fire through the propeller shafts of geared engines, it is proposed to arrange a firm attachment for the forward portion of the gun barrel in the casing carrying the propeller shaft. The gun may be clamped to this casing by means of a nut carrying a flame deflector. Arrangements for providing against loss of oil as described in Specification 414,287, of 1934, may be provided. In order to provide for the expansion of the gun when heated by firing, the rear fitting attaching the gun to the engine is arranged with a slider and guideways. A secondary or safety fixing may be provided to come into action after a breakage of the main fixing.

Autogiros

413,069. *Improvements in and relating to Aircraft with Freely Rotative Wings.* De la Cierva, J., Bush House, Aldwych, London, W.C.2 Dated March 13th, 1933. No. 7,623.

This specification describes methods by means of which the airscrew torque may be neutralised in autogiro aircraft of the type controlled by tilting of the rotor or controlling the pitch angles of the rotor blades. This is effected by arranging the slipstream to impinge on surfaces so that an aerodynamical couple may be produced neutralising the motor torque. These surfaces may be set at appropriate angles or may be of differing cambers and may consist of strut fairings, special surfaces, tail plane, etc. In order to prevent a yawing effect in such aircraft due to the slipstream impinging on a rear fin it is proposed to place fins on the extremities of the tail planes so that they are radial to the slipstream, so that the yawing effect is neutralised.

414,546. *Improvements in Aircraft with Aerodynamically Rotatable Wings and Power Plant therefor.* The Cierva Autogiro Co., Ltd., of Bush House, Aldwych, London, W.C.2. Convention date (U.S.A.), Oct. 28th, 1932.

This specification is concerned with methods of transmitting engine power to the autogiro rotor for starting purposes. The shaft driving the rotor is inclined upwards, and the gear for driving it may be either inclined upwards from the engine crankshaft, or parallel with the latter, the shaft in each case being geared to the crankshaft. If necessary, a bevel gear may be interposed between the engine and the shaft driving the rotor. A clutch is described for cutting out the engine, and also a special coupling of the slipping-tooth type for limiting the torque that may be applied to the rotor. The parts of the mechanism adjacent to the engine may be incorporated with the engine.

416,820. *Improvements in or relating to Aircraft.* Dr. Ing. Claude Dornier, Friedrichshafen, Lake Constance, Germany. Convention date (Germany), Feb. 16th, 1933.

In order to enable small wings to be used on aircraft for the purpose of increasing speed, and at the same time to enable the landing speed to be kept down to a safe figure, it is proposed to construct an aeroplane with the small wing area and to fit, in addition, a rotor of the autogiro type which may be placed inside the fuselage when the machine is in flight. The blades of the rotor may be attached to wires which are also attached to a sleeve on the shaft. On this sleeve being drawn down the blades are moved into a position parallel to the shaft, the whole arrangement being hinged so that it may then be swung into a position inside the fuselage. Or the blades may be moved into a position in line with the flight path so as to offer a minimum resistance.

Control of Aeroplanes

413,456. *Improvements in or relating to Means for Controlling Aircraft.* Tower, L. R., and Boeing Airplane Co., both of 200, West Michigan Street, Seattle, King, Washington, U.S.A. Dated April 19th, 1933. No. 11,486.

It is proposed to fit an auxiliary flap on aircraft controls. This flap is controlled by wires which are operated by the pilot and which are independent of the main controls, and the arrangement is such that the angle of the flap to the control surface remains constant whatever the position of the controls. This arrangement is intended to be used as a method of balancing the controls of an aircraft and is also to be used in cases where, owing to the stoppage of one engine of a twin-engined aircraft, there is a load on the rudder.

412,057. *Improvements in Aeroplane Construction.* Zap Development Corporation, Dunkalk, P.O. Baltimore, Maryland, U.S.A. Convention dates (U.S.A.), Aug. 8th, 1932, July 21st, 1933.

This specification refers to a method of lateral control of aircraft wings in which the aileron is separate from the wing itself and is hinged above the rear of the wing in the region where the airflow is downward. A preferred position is to place the aileron so that its nose is vertically above the trailing edge of the wing by about one aileron chord, though other positions can be used according to circumstances. These ailerons can be used with or without flaps of the Zap-type, which are stated to stimulate the flow round the ailerons, when pulled down, and it is also claimed that these ailerons affect the flow round the major aerofoil section, in addition to their own reaction. Full details of operating mechanism are given.

413,662. *Improvements in or connected with Aircraft.* L.P.R. Company, 277, Park Avenue, New York City, New York, U.S.A. Convention date (U.S.A.), Jan. 18th, 1933.

This specification refers to wing flaps of the type used to increase the lift of wings and which are hinged to the lower rear surface of the wing some distance in front of the trailing edge. In order to reduce the force required to operate these flaps it is proposed to arrange a connection between the rear of the flap when it is open and the trailing edge of the wing consisting of a flexible membrane in the form of a bellows which can be rendered approximately airtight. Arrangements are made so that when the flap is pulled down an orifice is opened. This latter projects forward into the air stream and communicates with the interior of the bellows so that the pressure produced by the velocity of the air assists the opening of the flap. When the flap is not in use the appliance folds back into the wing. The bellows is connected to the wing by an arrangement of chains so as to prevent bulging.

412,740. *Improvements in or relating to Means for Controlling Aircraft.* Tower, L. R., and Boeing Airplane Co., both of 200, West Michigan, Seattle, County of King, Washington, U.S.A. Dated April 19th, 1933. No. 12,441.

This specification refers to auxiliary flaps which may be mounted on the trailing edges of the rudder, elevators, or ailerons of aircraft for the purpose of assisting the pilot to move these controls, and also for the purpose of providing a bias when necessary, as in the case of the rudder of a two-engined aircraft with one engine stopped. The means for adjusting the flap is independent of the means for operating the control, and consists of cables and supports arranged in a parallelogram so that the flap is maintained at a constant angle to the centre line of the machine whatever the position of the control surface.

414,592. *Improvements relating to Automatic Controlling Devices for the Surfaces of Aircraft or Watercraft.* Siemens and Holske Aktien Gesellschaft Berlin-Siemensstadt, Germany. Convention date (Germany), May 11th, 1933.

In the case of aircraft equipped with an automatic pilot, apparatus is proposed by which out-of-trim conditions, such as that caused by the failure of one engine on a twin-engined aeroplane, may be compensated for by the action of an auxiliary device dependent for its action on the main automatic appliance. The auxiliary device preferably acts on auxiliary control surfaces such as the Flettner, though in the case of the elevator control it is preferred to alter the angle of the tailplane.

415,268. *Method of and Means for Increasing the Efficiency of Aerofoils and Hydrofoils and Reducing the Tendency of Aircraft to Stall.* Dr. G. D. Mattioli, 10a, Via Rogati, Padoa, Italy. Convention date (Italy), Sept. 9th, 1932.

This specification describes a proposed method of preventing the stalling of aerofoils by placing wires, lathes or bars in the neighbourhood of the leading edge in order to produce turbulence in the boundary layer. It is stated that, if the boundary layer is turbulent, the adherence of the fluid to the surface of the aerofoil is considerably reduced, thereby reducing the viscous effect exerted thereon by the main body of the fluid, this viscous drag having been found to be the chief cause of the premature detachment of the fluid currents.

414,378. *Improvements in or relating to Aircraft.* Abbott, E. D., and Baynes, L. E., both of E. D. Abbott, Ltd., Farnham, Surrey, and Travers, H. G., of Moor Cottage, Berkhampsted Common, Berkhampsted, Hertfordshire. Dated Feb. 1st, 1933. No. 3,090.

It is proposed to provide a cheap, compact and low-powered aeroplane suitable for dual control or solo flying by arranging that the pilot and passenger sit closely in tandem, the legs of the passenger being astride the back of the pilot. It is claimed that this arrangement makes the provision of a double set of instruments unnecessary and that one joystick only need be provided. Dual rudder controls are arranged for, and a disconnection gear may be fitted to them when the machine is used for tuition. Drawings are given of a tractor and pusher aeroplane constructed in accordance with the specification.

416,326. *Improved Control Surfaces for Air and Watercraft.* Hartshorn, A. S., The Royal Aircraft Factory, South Farnborough, Hants. Dated May 11th, 1933. No. 13,730.

In the case of ailerons which are balanced by displacing the hinge point rearwards and which have unsymmetrical leading edges, it is proposed to vary the shape of the leading edge along the span of the wing. For instance, the

aileron may have its nose coincident with the lower surface of the wing at the outboard end. At the middle of the aileron the nose may be coincident with the centre of the wing section, and at the inboard end the nose may be coincident with the upper surface of the wing. Thus, lines joining the leading edge of the aileron to the aileron hinge lie in different angular positions relative to the trailing portion of the aileron. Other methods of varying the nose section are proposed.

414,209. *Nozzle Gap Supporting Plane.* Knoll, J., 22, Enderstrasse, Breslau 10, Germany. Dated July 3rd, 1933. No. 18,854.

This specification is concerned with ailerons of the type in which the aileron is close to the plane in normal flight, but can be moved backwards when operated so as to leave a nozzle-shaped gap between it and the plane in front of it. The flap or aileron is supported by means of a sliding pivot or a system of pivoted links arranged so that the flap or aileron receives a motion compounded of a translation and a rotation for the purpose of enabling the aileron to take up a position (1) close to the wing for rapid flight; (2) spaced rearwardly from the wing so as to form a nozzle-shaped gap so as to increase the lift on the wing when starting; (3) spaced rearwardly from the wing and tilted thereto for slow flight and reducing landing speeds. In addition an auxiliary flap may be arranged in the aileron adapted to be pulled down so as to serve as a brake and also as a means of increasing the lift coefficient. Several methods of carrying out the movements by differing mechanical devices are described.

416,879. *Improvements in or relating to the Control of Aircraft.* Fairey, C. R., Cranford Lane, Hayes, Middlesex. Dated Oct. 26th, 1933. No. 29,736.

It is stated that in the case of aircraft with slotted wings the slots give an anti-spin yawing moment up to a fairly large angle of incidence, but that at larger angles the slot may aggravate the spin. In the case of a flat spin, opening both slots makes the spin flatten. Closing the inside one leads to a flatter and faster spin, while closing the outer slot reduces the spin. It is proposed, therefore, to interconnect the slots with the rudder so that the operation of this member may bring about the opening or closing of the slots as desired. Mechanism is described for the purpose of carrying this out and an arrangement is given by means of which the slots may be disconnected from the rudder bar at the will of the pilot.

416,813. *Improvements relating to Automatic Pilots for Aircraft.* Sperry Gyroscope Co., Inc., Manhattan Bridge Plaza, Brooklyn, New York, U.S.A. Convention date (U.S.A.), Sept. 2nd, 1932.

The object of this invention is to amplify and reduce the weight of automatic piloting apparatus and to enable such apparatus to perform its functions smoothly and without the use of electrical circuits. The apparatus described comprises the combination with a gyroscope, of differential flow means actuated by the movement of the aeroplane and the gyroscope, a hydraulic servo motor system for operating controls, the servo motor being controlled by hydraulic means pneumatically operated. The gyroscopes may also be used as directional indicators for the guidance of the pilot. The gyroscopic control may be cut out of action by the pilot when desired.

Engines

416,065. *Air-Cooled Engines for Aircraft.* Armstrong Siddeley Motors, Ltd., Green, F. M., and Reynolds, R., of Armstrong Siddeley Works, Park Side, Coventry. Dated Feb. 8th, 1933. No. 3,850.

In cases where air-cooled engines are fitted with ring cowling to reduce resistance, it is stated that there is difficulty in obtaining adequate cooling at

low air speeds owing to inadequate flow of air. It is proposed to provide the ring at its rear with a system of movable flaps which can be out-turned to induce an increased flow, and also to provide a ring of approximately aerofoil section, the boxes containing the valve gear being contained in this section. The ring is composed of two plates, one passing over the engine and the other under the valve gear boxes, the two being joined behind the engine. Alternative methods of operation are described.

413,349. *Improvements in or relating to Cooling Arrangements for the Cylinders of Internal Combustion Engines Used in Aircraft.* The Bristol Aeroplane Co., Fedden, A. H. R., and Owner, F. M., all of Filton House, Bristol. Dated Jan. 14th, 1933. No. 1,314.

As the blast of air near the centre of an airscrew has been found to be inadequate for the purpose of cooling the engine, it is proposed to provide a cooling fan, concentrically mounted on the airscrew shaft and driven by the engine for additional cooling purposes. The fan may be driven either at engine speed or faster than the engine by means of a gear.

Helicopters

413,336. *Improvements in or relating to Aircraft of the Helicopter Type.* Dr. Ing. C. Dornier, Friedrichshafen, Lake Constance, Germany. Convention dates (Germany), Jan. 16th, 1933, and Jan. 27th, 1933.

This specification describes a helicopter aircraft in which the lifting propeller or propellers are inclined forward in order to enable the aircraft to be propelled without an additional airscrew. The lifting propellers may be driven directly by an engine through gearing, or by means of a reactive method—air under pressure being allowed to escape through holes near the blade tips. In this latter case the air may be used for cooling the engine. The lifting propellers are so designed that they may autorotate when disconnected from the engine. Claims are made for methods of avoiding the turning effort of the propellers and also for the shape of the body of the machine and of the passenger accommodation. The blades of the propeller may be adjustable, and it is considered advantageous to provide the propeller blades with flaps, capable of being adjusted by the pilot, so that the power of each blade during each revolution is variable periodically.

413,941. *Improvements in or relating to Aircraft of the Helicopter Type.* Dr Ing. C. Dornier, Friedrichshafen, Lake Constance, Germany. Convention date (Germany), Feb. 17th, 1933.

In the case of helicopters in which the lifting propellers are driven by the reaction principle, it is proposed to hinge the blades on the horizontal axis in the known manner and to cover the joint with a flexible sleeve so that the joint is airtight. It is also proposed to use a broad basis for the hanging of the blades and also substantial stops, so that the wiring arrangement which, it is stated, is often used with such machines to limit the travel of the blades, may be dispensed with.

413,184. *Improvements in or relating to Rotatable Supporting Wing Arrangements for Aircraft.* Dr. Ing. Claude Dornier, Friedrichshafen, Lake Constance, Germany. Convention date (Germany), Feb. 2nd, 1933.

In the case of lifting propellers for helicopter aircraft driven reactionally by air jets rotating with the propeller, it is proposed to provide means by which these jets may be moved so that the plane in which they act no longer coincides with that in which the propeller rotates. This is accomplished by arranging a manual control so that these jets may be operated together or separately.

415,917. *Improvements in or relating to Aircraft Provided with Rotatable Wings or Blades.* Dr. Ing. C. Dornier, Friedrichshafen, Lake Constance, Germany. Convention date (Germany), Jan. 26th, 1933.

In the case of helicopter aircraft it is proposed to use two co-axial lifting screws, one of which may be driven by the engine which is connected to it by a clutch, or it may be driven by the reaction principle. The other screw may be allowed to rotate freely or may be driven in either direction by the engine, also through a clutch. The screws may be revolved round their longitudinal axes or moved out of their plane of rotation or out of their radial positions.

414,399. *Improvements in and relating to Helicopter or Rotative Wing Aircraft.* Bechert, P., and Schmidt, R., of Saag, Czechoslovakia, and of Schönbühel, near Melk, Lower Austria, respectively. Dated Oct. 31st, 1932. No. 30,584.

A helicopter lifting screw arrangement is described in which there are two lifting screws, one surrounding the other, the first being of annular form. The screws are so designed that approximately the same rate of downward flow is maintained over the combined disc. It is claimed that this arrangement increases efficiency and gives stability to the aircraft. A captive helicopter with this arrangement is described.

Instruments

416,766. *Control Indicator for Aircraft.* Cebrelli, M., Aeroporto di Elmas, Cagliari, Italy. Dated Dec. 18th, 1933. No. 35,638.

It is proposed to provide a control indicator for aircraft which comprises in the instrument board of the aircraft a central dial with the indices of the banking and turning indicators and the indicators of the horizontal and climbing speeds, and two adjustable indicators at the sides of the central dial, which allow the values of the horizontal and of the climbing speeds to be predetermined. The horizontal and climbing indicators are provided with anemometric capsules actuating a lever the motion of which is transmitted to the needle of the indicator. There is also on the spindle a disc with concentric and oblique grooves which operates a lever connected to the central air speed indicator.

Model Aeroplanes

413,466. *Improvements in Toy Aircraft.* Wilmot, Mansom and Co., Ltd., and Bristow, J. W., Triang Works, Morden Road, Merton, London, S.W.19. Dated May 3rd, 1933. No. 12,937.

This is an arrangement intended to prevent damage to the propeller of a toy aeroplane on crashing. The device permits the propeller to pivot on its spindle if it receives a hard blow, and consists of a spindle in wire bent into an eye at the propeller end, which eye fits into a nick on the propeller. It is secured in position by a separate clip made of sheet metal which is, in its turn, covered by a cap, the last two members being secured to the propeller by a separate pin.

Ornithopters

415,566. *Improvements in or relating to Ornithopters.* Verdier, P., 70, Fauberg Saint-Jean, La Puy (Haute-Loire), France. Convention date (France), July 20th, 1932.

The machine proposed is an ornithopter having two sets of wings, one behind the other, arranged to beat alternately, so that, it is stated, the propulsion and support are continuous. The wings are caused to beat by engine power,

but it is claimed that they will continue to beat when the engine is stopped. The twist of the wings while beating is controllable by the pilot.

Seaplanes

413,472. *An Elastic Connecting Device between the Floats and the Body of a Water Plane.* (Madame) Y. L. Messier, 179, Boulevard Brune, Paris, France. Convention date (France), May 14th, 1932.

This specification describes a means of constructing a chassis for float seaplanes in such a way that the strut legs themselves become the shock-absorbing members. The body is connected to the float solely by these shock-absorbing members, though these members may be stabilised structurally by stays. The front shock-absorbing strut may be attached rigidly to the fuselage or wing with its movable part jointed upon the float, while the rear shock-absorbing strut may be jointed to the fuselage and to the float. Longitudinal play is provided for in the joints where necessary.

Seaplanes and Flying Boats

415,736. *Improvements in or relating to Seaplanes.* Dornier Metallbauten G.M.B.H. and Dr. Ing. C. Dornier, Friedrichshafen, Lake Constance, Germany. Convention date, March 3rd, 1914.

In this specification it is proposed to obviate the necessity for fitting the engines and propellers of seaplanes high in the structure. It relates to seaplanes having at least two propellers, one on each side of the structure. These propellers are fitted approximately in line with the chord of the wing, and are in such a position that they would normally dip into the water. In order to do this the propellers are arranged to be swung upwards from a centre, but an arrangement may be incorporated by which they are also vertically displaced. Wing floats may be arranged to fold into the engine nacelles, and the mechanism controlling this may be interconnected with the mechanism for swinging the propellers.

REVIEWS

Airships in Peace and War

By Capt. J. A. Sinclair. Published by Rich and Cowan. Price 18/-.

Capt. Sinclair was Executive Officer at Polegate Air Station, and his book contains an authoritative account of the general history of airships, with special reference to the development during the war and afterwards. He is, as might be expected, a firm believer in the airship, and although his advocacy is naturally *ex parte*, he has made out a strong case for the retention of airships for certain service duties.

As he points out, the airship was particularly useful during the late war for convoy duties, and also took a considerable part in the anti-submarine campaign. Its power of hovering like a hawk over its victim while delivering the *coup de grace* in the shape of a well-directed bomb accounted for many of these raiders, while the large duration of flight peculiar to the airship was also most valuable. In fact the author believes that the airship is the natural antidote to the submarine, and that duties of this nature cannot be satisfactorily carried out by either aeroplanes or seaplanes.

Whether he is right or wrong on this matter, it is in his favour that the airships required for this purpose are comparatively small and cheap and that their existence would permit the training of crews. It is always possible that circumstances will occur in the future which will make it advisable to construct large rigid airships, possibly for scouting with the Fleet, and at the present moment we should find it even more difficult to provide the crew than to build the ship itself. Experience is essential, and the freedom from accident of the Zeppelins during recent years is doubtless largely owing to the thirty years of experience that the Germans have had in the handling of ships of this type.

But experience with a small airship is better than no experience at all, and adding to this the fact that the airship has shown itself to be of definite use as a fighting unit, the case for building them would appear to be strong. The author has written a book which required writing, and has done it well.

Properties and Strength of Materials

G. I. D. Haddon. Published by Sir Isaac Pitman. 8/6 net.

This book, now in its second edition, is the third volume of a series which deals with the design of structures and is intended for those engaged in aeronautical drawing offices who may not have had the advantage of a higher technical education and yet wish to know the why and wherefore of what they are doing. For this reason the methods of calculus are strictly barred from the work.

Mr. Haddon has got over the difficulties imposed by this limitation extremely well, but I think it would be worth while giving a few calculus proofs in an appendix in order to encourage readers to study this method of calculation.

The book should fulfil its purpose admirably, the reading matter is clear and the diagrams are well chosen, and the scope of the book, which extends from elementary matters to the theorem of three moments and the various strut formulæ, is well chosen. There is little to criticise, but the statement on page 1 that the cohesive forces between molecules decrease with the distance between them seems difficult to reconcile with the existence of Young's Modulus.

Elementary Quantum Theory

By R. W. Gurney. Cambridge University Press. Price 8/6.

This book is of peculiar interest. The reader acquainted with the ordinary theories of mechanics is introduced into a world where these theories no longer apply and where there is no certainty of anything being in any particular state or position. So the discussion is directed solely to the probabilities of something particular happening, and it is the consequences arising from the equations representing these probabilities which are of such importance in the comprehension of the state of affairs in the molecule of a substance. The keynote of the methods used consists in energy changes, such ideas as attraction and repulsion between particles being obsolete for this purpose, but the general result is a picture of the relations between atoms, electrons, etc., and the effect on them of disturbances, which is not only in accordance with observation, but which has added much to our knowledge of the structure of molecules.

There is no question that the problems of strain in materials are, in the limit, a matter which concerns the molecule, and it would seem that it is to quantum theory that the engineer must turn if he wants to understand exactly what is happening when a metal is strained. There is one hint on this matter in this book which may be the germ of a considerable extension of knowledge.

The book is not difficult to read, but would be even easier if the author would adopt the custom of most aeronautical books and devote a page to the complete list of symbols used and their definition. On page 7 lambda is mentioned and the meaning of this symbol is only referred to a few pages later in the letterpress. Nor are the meanings of e.s.u. or e.m.u. explained for example. Terms

which are well-known in one branch of science or engineering may be quite unknown to workers in other branches.

The subject generally is one which those who wish to be abreast with modern thought cannot neglect, and the book is admirably adopted to act as a preliminary textbook.

Air Licences

By T. Stanhope Sprigg. Sir Isaac Pitman and Sons, Ltd. Price 3/6.

As there are no less than 21 licences and certificates connected with civil aviation, and as most of those who earn their living or derive recreation from this form of transport have to be in possession of one or more of these documents, there is certainly scope for a book which explains how they may be obtained, especially as the obtaining is not usually a simple matter.

The pilot may hold any of three different licences and, if he wishes to instruct in piloting, must possess a fourth, while the ground engineer has his choice of five different categories, the last of which is divided into five sections. There are also licences for parachutists, balloon pilots, airship pilots, wireless operators and navigators and, in addition, there are certain certificates which are granted by the Royal Aero Club.

For each of these the requirements naturally differ, but the authorities require to be satisfied that the applicant possesses sufficient skill, knowledge and experience of the subject for which the licence is granted. Full details of these requirements will be found in this book, frequently in the form of abstracts from official documents, but the author has added much which elucidates the complication of official phraseology.

Individuals who are desirous of qualifying for any of these licences will find this book most useful. Much of the information given is nearly inaccessible to those who do not know where to look for it.

CORRESPONDENCE

To the Editor of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

Hebrew Technical Institute, Haifa,

August 23rd, 1934.

Dear Sir,—In the introduction to his paper, " The Nature of the Torsional Stability of a Monocoque Fuselage," K. Sezawa refers to my paper " Die Torsionsstabilität des dünnwandigen Rohres " (Proceedings of the first International Congress for Applied Mechanics, Delft, 1924, and Z.A.M.M. 5 (1925) 235/243) saying that " owing to the certain apparent particularities on his part his solutions of equations are open to grave doubts."

Asked to specify his doubts, Mr. Sezawa wrote the following to me (literally):—

" Your method of obtaining simply $(m_1 - m_2)$ from the equation (V) (Z.A.M.M., *loc. cit.*) is not perfect because the equation (V) is 2×4th degree in m in general and the condition (VI) is arbitrary, so that the curves in Abb. 2 are not applicable to general problems.

The boundary conditions in your case are not sufficient so that your result is completely ambiguous. How would you solve the determinate problem with satisfactory end conditions (two kinds of end conditions for plates, etc.) on the line of your method of treatment?"

In reply:—

The principal aim of my paper was to calculate the smallest critical twisting moment possible for tubes of middle or large length ($l/a = C/a \geqq ca \,.\, 5$) putting the displacements in the form (3) first given by myself. That aim has been completely reached by the values of the curve Abb. 3, the calculation of which is independent of any boundary condition at the ends of the tube.

But it was not my intention to calculate the numerical values of the critical twisting moment for the very short tubes studied by Mr. Sezawa, the boundary conditions in this case being of great influence.

In consequence hereof, the example (VI)—consciously chosen as simply as possible and, therefore, having only one boundary condition $W=0$ and only real values of m—only was to illustrate the graphical method used by myself and appliable even in the most general case, as shown afterwards.

However, this simple particular solution is not ambiguous; for it represents the case of a tube, the ends of which are supported, and clamped in a manner completely determined by the ratio G_1/w' which for each value of ϕ in $\xi = \pm l/a$ may unequivocally be calculated from the equations (I), (IV), (VI), (VIIa) and Abb. (2a)-(2d).

Now, I should like to prove that the graphical method applied by myself may even be used in the general case of complex roots of (V):—

Putting $m = a + b \,.\, i$ (a, b real) c_0 may be got from (V) in the form:— $C_0 = F_1(a, b^2, \epsilon, n) + ib \,.\, F_2(a, b^2, \epsilon, n)$, F_1 and F_2 being algebraic functions of (a, b^2, ϵ, n). As c_0 must be real we have the condition:—

$$F_2(a, b^2, \epsilon, n) = 0 \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$\text{and } c_0 = F_1(a, b^2, \epsilon, n) \quad . \quad . \quad . \quad . \quad (2)$$

From (1) we may calculate the value of b^2 for any value of a—which is best simply done by trying—and draw the curve $F_2(a, b^2, \epsilon, n) = 0$ of Fig. 1.

By means of this curve it is then possible to eliminate b^2 in $c_0 = F_1(a, b^2, \epsilon, n)$ and to get c_0 as a function of a alone (besides ϵ, n) in the form of $c_0 = F_1(a, b^2, \epsilon, n) = \phi(a, \epsilon, n)$ graphically represented by Fig. 2.

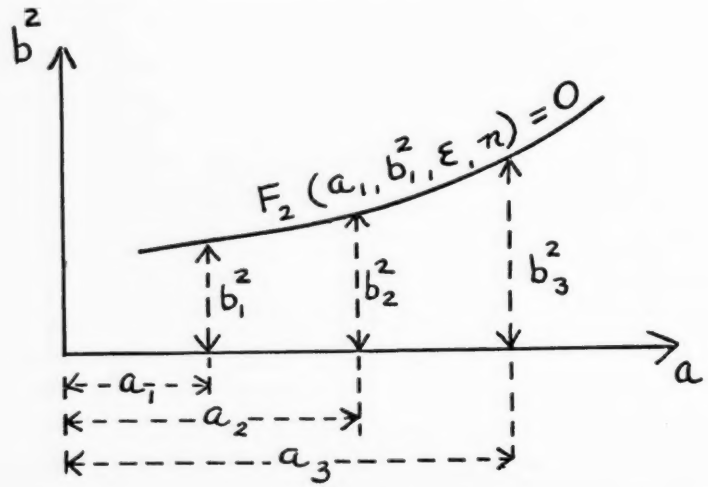

FIG. 1.

* The form of the curve Fig. 1 is only provisionally assumed.

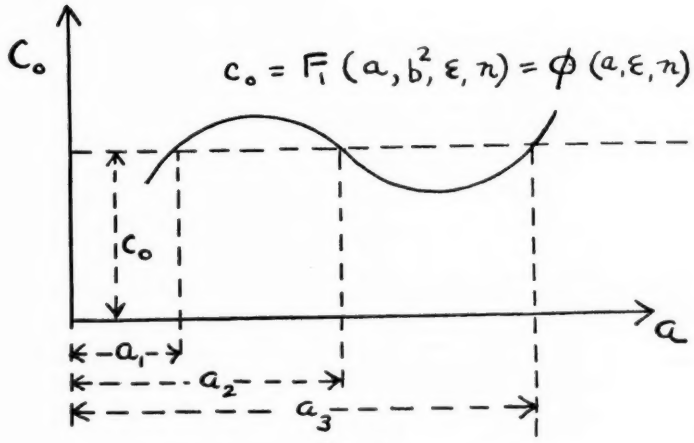

FIG. 2.

Now—if, *i.e.*, two roots $m_1 m_2$ of (V) are real and six: $a_1 \pm b_1 \cdot i$; $a_2 \pm b_2 \cdot i$; $a_3 \pm b_3 \cdot i$ complex—we are able to find the former from Abb. (2*a*)-(2*d*) of my paper and the latter from Fig. 2 by determining $a_1 a_2 a_3$ graphically for any assumed value of c_0 and, then, taking b^2 from Fig. 1.

After this, we must vary c_0 so long until the condition of stability, *i.e.*, for the clamped tube ($w=0$, $w'=0$) condition (VII*b*) is satisfied, which always will be possible by applying a suitable method.

In opposition to the opinion of Mr. Sezawa, we see that the Abb. (2*a*)-(2*d*) derived without any boundary condition are always appliable for graphically determining the real roots m of (V); it must only be completed by Fig. 2 in order to find the complex roots $a \pm b \cdot i$ of (V).

Believing that after this argument the results of my paper can no longer be doubted, I may be allowed to add some critical remarks on Mr. Sezawa's paper:—

With regard to the supported tube, he simplifies the boundary condition $G_1=0$ into $d^2w/dx^2=0$ neglecting the influence of Poisson's ratio σ. In my paper having proved that this influence is very great for the critical moment, I doubt whether it is permitted to omit the terms containing σ in the boundary conditions.

Besides, in his equation (3) of equilibrium the term:—T_2/a is lacking. By adding this term, the first element of the third line of (11) does not disappear and (12), (13), and the whole following calculation becomes much more complicated. I believe it possible that this lacking term may be of great importance and that, chiefly owing to the above mentioned facts, the experimental results differ so much from Mr. Sezawa's theory; for I cannot agree with Mr. Sezawa's opinion that the differences of Table V of -20, $+89$, -33, -38, -37, -71 per cent. of the calculated from the experimental results may be regarded as small discrepancies.

I have forwarded a copy of this letter to Mr. Sezawa.

Hoping that according to your kind letter you will publish this answer in your Journal as soon as possible, I remain, dear Sir, with many thanks,

Yours sincerely,

E. SCHWERIN.

To the Editor of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

Dear Sir,—Are not the phenomena described by Prof. B. Melvill Jones in his Wilbur Wright Memorial Lecture (September, p. 760) the same in essence as the familiar alternating " eddy street " behind a cylinder? In the case of a symmetrical body of bad aerodynamic shape, such as a cylinder, if the Reynolds number is high enough, some small irregularity in the airflow decides on which side an eddy shall develop. The presence of this eddy then brings about circumstances favouring the development of the corresponding eddy on the other side; and the process then repeats, at regular intervals, as long as velocity, etc., are unchanged. In the case of a body of good shape, if it be symmetrical (a tailplane, for example), the alternating eddies presumably still develop; but *they are small and consequently their period is short, so that the forces on the body appear to be constant* by any ordinary method of measurement. In the case of an asymmetrical body of good shape, such as an aerofoil at a small angle of incidence, it appears from Prof. Melvill Jones's investigations that only the one eddy—that near the trailing edge—can develop. It is small, and therefore the drag due to it appears constant, as above. When the aerofoil is stalled, the conditions become such that the other eddy, behind the leading edge, is more and more likely to develop; and it does so suddenly when a chance variation of the airflow temporarily favours its appearance. The two eddies then alternate, as they would behind a cylinder; except that, owing to the asymmetry of the body, they are of unequal size and shape, and therefore presumably of unequal period. The larger will persist for longer at a time than the smaller, if conditions favour equally the development of either. If conditions do not, then the flow may be highly irregular, one eddy repeating itself over and over again, with an occasional intervention of the other eddy when conditions temporarily favour it.

My experimental equipment consists only of a miniature wind tunnel (constructed under the influence of Mr. Farren's interesting and beautiful lecture, reported in this Journal in June, 1932), and I cannot carry the matter further; indeed, I had hoped that someone more able to deal with it would have raised the point. That it represents the facts is supported by Mr. Farren's observation (*l.c.*, Fig. 14, p. 466, June, 1932) that at low Reynolds number stalling begins at a lower angle of incidence than at high Reynolds numbers. This, presumably, represents the condition under which a cylinder trails two symmetrical eddies instead of alternating ones.

Yours faithfully,

(Miss) A. D. BETTS.

To the Editor of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

Dear Sir,

Miss A. D. Betts' letter of October 11th.

Since any change of lift in an aerofoil is necessarily accompanied by a change of circulation and a consequent shedding of vorticity, Miss Betts is certainly correct in associating the alternations of force, which I described in the Wilbur Wright Lecture, with the alternate shedding of eddies. The phenomenon is, however, very different from the regular shedding of alternate eddies which occurs at very high incidences. The intervals between alternations, expressed in terms of distance travelled by the aerofoil, are much longer and more irregular than those associated with the formation of the familiar Kàrmàn street, and the phenomenon is more easily described in terms of two alternative flow patterns, either of which can persist for a relatively long time, but eventually gives way to the other. Using high frequency recording lift balances, we have recently obtained records of the fluctuations of lift and drag whilst aerofoils move at various rates through the critical incidence region, and the difference in the form of the alternations from those which, at higher incidences, are due to the regular shedding of alternate eddies, is very marked.

Yours faithfully,

B. MELVILL JONES.

THE ROYAL AERONAUTICAL SOCIETY

The Fourth Annual Joint Meeting held by the Royal Aeronautical Society, the Institution of Automobile Engineers, the Institute of Fuel, the Chemical Engineering Group, the Diesel Engine Users Association, the Institute of Marine Engineers, the Institution of Mechanical Engineers, the Institution of Petroleum Technologists, the Junior Institution of Engineers, the North-East Coast Institution of Engineers and Shipbuilders, and the Society of Engineers, was held in the Lecture Hall of the Royal Geographical Society on Tuesday, March 6th, 1934, when a paper on the "Causes of Detonation in Petrol and Diesel Engines," by G. D. Boerlage and Dr. W. J. D. van Dyck was read.

In the chair: Mr. L. H. Pomeroy, President Elect of the Institution of Automobile Engineers, during the reading of the paper, and Mr. D. R. Pye, Member of Council of the Royal Aeronautical Society, during the discussion.

CAUSES OF DETONATION IN PETROL AND DIESEL ENGINES

BY

G. D. BOERLAGE[1] and DR. W. J. D. VAN DYCK[1]

Many types of detonation[2] may be distinguished, and the causes are to be found in the engines as well as in the fuels. Obviously one single cause would not be expected to be found, but, on the contrary, quite a number of properties which will be more or less of influence under different engine conditions. These may differ widely, yet there is more unity in the multitude of causes of detonation than might be expected, and this the authors will endeavour to illustrate. They must apologise for mentioning many well-known, in addition to new, views, but it is necessary to do this for the general exposition of the material.

Two principal types of engines should be considered to-day:—

(1) That in which the fuel is added to the air at the end of compression (in air compressing or Diesel engines), and

(2) That in which the fuel is added to the air before compression (mixture compressing, *e.g.*, petrol engines).

Most methods of increasing the output of petrol engines seem to attract the "demon of knocking"; the reverse is true for Diesel engines, which is hopeful for their future development.

At first sight it might be concluded that, in the case of Diesel engines, requirements would be satisfied by compressing the air until the auto-ignition temperature of the fuel is attained, and that in the case of petrol engines it would be desirable to compress the mixture to a temperature just below the auto-ignition temperature.

But these two conclusions are fundamentally wrong. This requires a closer investigation of what happens in internal combustion engines.

[1] Of Bataafsche Petroleum Maatschappij, Delft, The Hague, Holland.
[2] See Appendix.

The simplest representation of what happens in Diesel engines will first be considered. Fig. 1 shows schematically the successive positions of a single fuel charge. Supposing that ignition occurs only after great delay; for instance, when the fuel has reached the position C, it will be clear that by that time there will be so many fuel particles simultaneously in the same critical condition of auto-ignition that a heavy explosion from what will be called the " primary gas "[3] may be expected. If, on the other hand, ignition starts in the position B, there will be only a very slight explosion of the " primary gas," the rest of the fuel being fed into the flame formed by the explosion and burning gradually. Thus, the delay appears to be decisive for the fierceness of the knock, since it is decisive for the quantity of " primary gas."

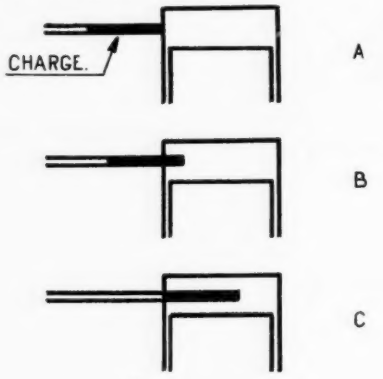

FIG. 1.
Fuel admission in Diesel engine.

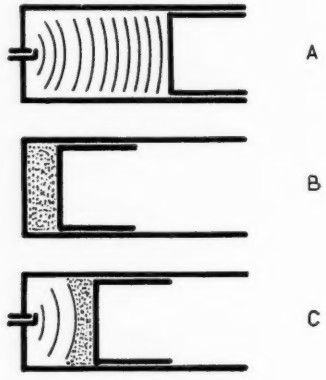

FIG. 2.
Modes of combustion.

Although this view on combustion in Diesel engines is rather primitive, it is really very useful, as it points to the main direction in which knock may be avoided; all that is possible must be done to promote immediate ignition of the fuel which first enters; for instance, extreme air temperature far beyond the auto-ignition temperature of the fuel will shorten delay.

The simplest representation of what happens in petrol engines will now be considered:—

Fig. 2 shows schematically three similar petrol engines having different compression-ratios. The first, A, has a very low ratio; the second, B, an extremely high one, and the third, C, a more normal one. The first shows a progressing flame, starting at the spark and burning in a quiet way. The second shows the other extreme. If compression is high enough it can be imagined that, even without a spark, combustion will take place at once, starting practically at the same moment at every point of the compressed charge (in a manner very similar to that shown by Fig. 1, C) and that a heavy explosion may be expected. The third shows what happens in practice, namely, a double form of combustion is observed; the progressing flame is seen first; it compresses the unburnt part of the charge, which will be called " end gas,"[4] to an extent which suggests a compression-ratio due to the flame. Of course, this compression-ratio of the flame is a fictitious conception, quite different from the compression-ratio of the engine, for example the flame " compresses " a diminishing quantity of mixture, the piston a constant one, etc. Yet the notion of a " flame compression-ratio,"[4]

[3] See Appendix.
[4] See Appendix.

as against an " engine compression-ratio " is a practical one, as it indicates the quintessence of the problem.

Through " flame compression " the " end gas " is brought into very much the same condition as the total mixture in case B, Fig. 2, and explodes. The larger the quantity of exploding end gas, the severer the knock.

There is an essential difference between a high " flame compression " and a high speed of the flame front. As the end gas explodes only after a certain delay, it might even be concluded that in an extreme case a high flame speed would reduce the quantity of end gas to a negligible quantity before it explodes. Speeding up the flame without activating the end gas may be effective as long as it does not lead to rough running (*e.g.*, through turbulence), often, however, higher flame speed corresponds with disproportionately greater danger for the end gas.

Although this view on combustion in petrol engines is also rather primitive, it is very useful, in that it shows how to avoid knock as far as possible by improved construction, *e.g.*, by cooling the end gas.

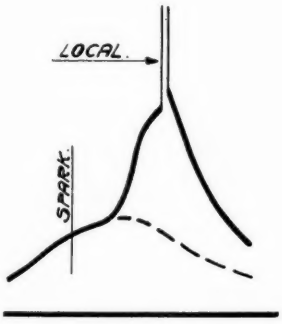

FIG. 3.
Petrol-knock.

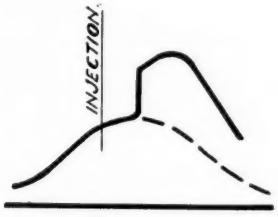

FIG. 4.
Diesel-knock.

The following sketch shows the typical difference between the rapid pressure rise in the petrol engine at the end of combustion (Fig. 3) and that in the Diesel engine before combustion (Fig. 4).

It will be clear now why the two conclusions mentioned in the beginning are fundamentally wrong. As a matter of fact, in the case of the Diesel engine the question is not whether ignition will occur or not, but whether it will occur early enough to avoid knock (sufficiently short delay, small quantity of primary gas), and in the case of the petrol engine the question is not whether auto-ignition will be caused by piston compression directly, but whether it will be sufficiently avoided in the end gas (sufficiently long delay, small quantity of end gas), which is compressed by the burning gases to a ratio which has been called the " flame compression-ratio " and which may be twice the " engine compression-ratio." This explains why for petrol engines a compression-ratio of 6:1 is considered high, whereas auto-ignition would occur only at a ratio of about 9:1, and why for Diesel engines this ratio of 9:1 is far too low, 14:1 being an average. It also explains why the " demon of knocking " seems to be more attracted by petrol engines than by Diesel engines, as said before.

The following conclusions are now arrived at:—*To avoid knock, in the Diesel engine compression must be taken far beyond the point corresponding to the temperature of auto-ignition in order to have admissible short delays, and in the*

petrol engine compression must only be taken to a temperature far below that of auto-ignition, as an excessive "flame compression-ratio" must be avoided.

However, these two conclusions should not yet be regarded as quite definite, and the matter must be investigated more thoroughly.

Again, first consider the Diesel engine. Of course, for good efficiency, good mixing is required, but for good mixing time is required, be it a very short time. Fig. 5 shows four conditions of Diesel mixtures which are fundamentally different. A difference may be made between fine and rough atomisation, and between even and local distribution of the fuel in the air. The degree of atomisation may be designated as good or bad *micro-mixture*, and the degree of distribution as good or bad *macro-mixture*.

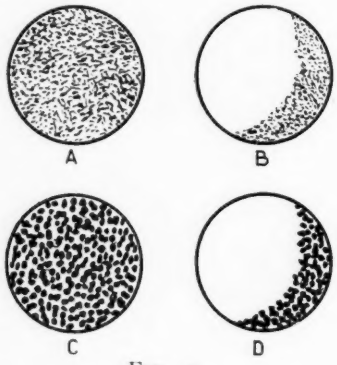

FIG. 5.

"Macro" and "micro" mixtures.
A = good micro, good macro.
B = good micro, bad macro.
C = good macro, bad micro.
D = bad macro, bad micro.

Tests have shown that for high mean effective pressure a good macro-mixture is of the utmost importance, and of more importance than good micro. Now, if an extremely short delay in an engine has been secured, it is quite possible that knock will be completely avoided, for the reasons given above; but at the same time the defect of bad macro-mixture (distribution) may have been introduced, as the fuel that was ignited immediately after entering the cylinder may hamper the rest of the fuel in finding fresh air for combustion. This will cause smoke and smell, high consumption, low mean effective pressure, etc. In such a case it would have been better if there had been more delay; that is, more time for the fuel molecules to find their air-partners before they risk being isolated in burnt gas. Another disadvantage of extremely short delay may be the tendency to burn too near the nozzle, thereby causing local overheating and carbonisation of the nozzle. Yet it would not be correct to go so far as to say that the longer the delay the better the mixture or the less carbonisation, since long delays increase the time of contact of fuel and cooled walls, which as far as the authors know has only disadvantages. Thus engine conditions should be arranged for shortest delay, so far as such is possible without involving its more or less inherent disadvantages. A strong swirl, as, for instance, in the "Comet head" engine, may help to fulfil these requirements.

Considering now the petrol engine, protection of the end gas against too high a compression-ratio of the flame front should not be exaggerated. Especially

in automobile engines a small amount of detonation at full load should be considered as not undesirable. It is not only the Highest Useful Compression-Ratio, the H.U.C.R., as defined by Ricardo, which stresses these points; as a matter of fact, this H.U.C.R. may be found by setting the engine until a certain degree of light knock is heard. Another advantage of slight detonation is its healthy action in cleaning the combustion chamber. It is well known to drivers of sports cars that an engine that has been running at low load for a long time may often be found considerably improved after a short run under full power. As an extreme case the authors have demonstrated that the head of a Ford engine covered with a layer of hard carbon almost 2 mm. thick could be cleaned of practically every particle of this carbon by running the engine for 10 min. at full load on the most abominable petrol that could be found as regards detonation; the detonation, of course, was beyond description. The authors would not advise anybody to apply this method in practice, or at least if it is done, the lubricating film should be restored by excessive lubrication for a few seconds. But the test shows that slight detonation for short periods at full load may be useful, especially in underloaded engines; it may help to fulfil the function of self-cleaning—at least it may be considered as an accompanying phenomenon of sound combustion conditions. Of course, this detonation is not the only factor promoting self-cleaning; swirl is another, and a better one, but this problem will not be discussed now. The authors wish to draw attention to this important *principle of self-cleaning*, which can be readily detected in all organisms; engines, animals, organisations, and even governments cannot live long without it!

On the other hand, detonation in petrol engines may, of course, be diminished by special means, but these means have certain inherent disadvantages. For instance, detonation may be greatly repressed by a strong swirl; the swirl whirls away the end gas and thus protects it against an excessive compression-ratio of the flame front. But it is well known that the disadvantage inherent to the swirl is its tendency to exaggerate the speed of combustion; excess of swirl will cause "bumpy running."

It will be clear now why the conclusions given above are as yet not quite definite; *shortest delay and exaggerated protection of end gas imply inherent dangers; the cure may be worse than the disease.*

Basic Principle of Knock

This is not the place to consider in detail the various means that may be deduced from the above-given considerations for improving combustion in engines, and attention must be concentrated on the character of the knock. There is certainly not one single type of knock, just as there is not one single cause of knock, but they are all more or less related to each other, as the authors will attempt to illustrate.

The basic principle of knock is vibration; no knock without vibration. And thus two questions present themselves:—

(1) What is going to vibrate?
and (2) Why is it going to vibrate?

The origin of vibration is too sharp a change of force. Excluding engine knocks which are due to worn cams, a loose flywheel, etc., those set up directly by the change in pressure of the charge may be considered at once.

What is Going to Vibrate?

It may be the charge itself, the frame and the walls (*e.g.*, the piston crown), the piston with all that is directly or indirectly connected to it—to be complete, it might be added, the piston of an indicator and what is connected to it.

The indicator piston will first be considered. A pencil indicator diagram of a slow running Diesel engine may have the well-known shape represented in Fig. 6. If combustion is rough, the diagram will take the shape represented in Fig. 7, which shows the fact that the indicator piston is moving as an oscillating mass attached to the indicator spring; apparently the pressure change was too sharp for the indicator. Even a steam engine may show this indicator fault. That in the case of Fig. 7, the broken line is due exclusively to this cause, and not to any problematic combustion waves during the expansion, was proved by striking the indicator piston lightly at the right moment by a special mechanical device when the engine was showing the diagram of Fig. 6; immediately the diagram, Fig. 6, changed to practically the shape of the diagram Fig. 7. As a matter of fact, the diagram in the case of Fig. 7 when taken with a more "rapid" indicator, appears to have very much the same shape as the diagram in Fig. 6. The maximum pressure is really much lower than Fig. 7 would suggest.

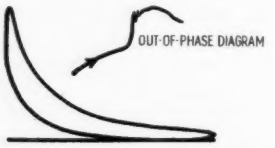

FIG. 6.

Knock registered by fast indicator.

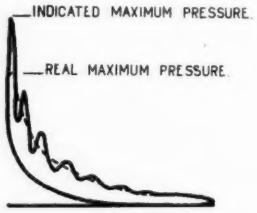

FIG. 7.

Knock registered by slow indicator.

Practically the same phenomenon may occur with the engine piston. Of course, periods and amplitudes of vibration are quite different. Supposing, for instance, that the engine piston is at top-dead-centre, and an explosion occurs while the engine is not rotating; it is quite clear that a very flexible shaft may fulfil, by bending, the rôle of the indicator spring and vibrate with the piston vertically, whereas a very rigid shaft may show no effect. Supposing, with the explosion occurring while the engine is not rotating, that the crankshaft is 90 deg. before top-dead-centre, then torsional vibration of the shaft may be set up, including movements of piston, piston-rod, shaft, flywheel, and all that is connected to it. Moreover, vibrations of these parts one against the other may be observed with all kinds of periods and intensity. Fundamentally, rotation of the engine would not interfere with the development of these vibrations.

Knock and "Bumpy Running"[5]

The first supposition (crankshaft at top-dead-centre) with rigid crankshaft may correspond to what the authors would like to call "knock." The same supposition (crankshaft at top-dead-centre), but with very flexible crankshaft and the second supposition (crankshaft at 90 deg. before top-dead-centre) may correspond to what is known as "bumpy running." Of course, all kinds of transition between these two cases will occur.

As an illustration, the following test may be described:—The timing of the spark of a knocking petrol engine was gradually made earlier. Fig. 8 shows schematically the intensity of knock and bumpy running against the successive timings (crank angle). The engine has an electric brake which will motor the engine when the speed tends to fall, so that constant speed is maintained. First knock was heard and the diagram showed a vertical pressure rise at about top-

[5] See Appendix.

dead-centre; then with earlier spark, knock increased, and a beginning of bumpy running could be noticed. After passing through a maximum, the extremely heavy knock decreased while bumpy running increased. Finally knock disappeared, and so did the bumpy running after having passed through a maximum. Thus the engine was then running quite smoothly, notwithstanding the fact that pressures were extremely high. An analysis of what happened made it clear that at this extremely early setting of the spark, the charge was burnt gradually, at the beginning of the compression stroke. The high temperature, due to combustion, thus existing right at the beginning of the compression, explains the extremely high maximum pressures at top-dead-centre; but the pressure rise could be smooth (as in a highly-compressed Diesel engine, when stopping injection); practically no vibration was set up and no bumpy running was heard.

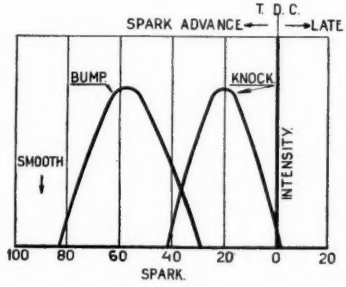

FIG. 8.
Knock and bump intensities.

The period of oscillation of the moving parts is rather long; a rather slow change in pressure rise may suffice to cause intolerable oscillation, but the change should be an important one, for the masses are heavy. Here is a great difference from what is required to set the walls in vibration; their period being very short, a very rapid change in pressure rise is required, but a small one may suffice, for the masses are light. For an automobile engine, in the case of a crankshaft with attached parts as piston, piston-rod, etc., a period of 0.01 sec. might be estimated for torsional vibration as against a period of 0.001 sec. for bending vibration of the same, and up to 0.0001 sec. for a vibration of walls. The vibrations in the charge itself may be estimated here to have about the same period as the walls.

Of course, these figures have only a schematic value, but they show that really extreme speeds of change of pressure must be looked to to explain vibrations of the walls and the charge.

In Search of Causes of Extremely Rapid Pressure Rises

Relatively slow changes in pressure will not be considered, and the main causes of the extremely rapid ones will be investigated. It has been assumed in the beginning that compression beyond the auto-ignition temperature would cause combustion to start practically at the same moment in every point of the compressed charge, which would mean *simultaneous combustion*[6] (not necessarily instantaneous). Considering this assumption now more accurately, it is found that the phenomenon is more complicated. Of course, conditions at every point are not the same, as the fuel is far from homogeneous and the distribution of fuel and of temperature in the charge is irregular. Knock should not be described as the effect of simultaneous combustion without further explanation. This

[6] See Appendix.

should not be understood as if at one and the same moment every molecule of the fuel is burnt. On the contrary, it means that at one and the same moment at many spots in the charge, a particularly critical stage is reached, as highly activated molecules have developed flame nuclei, from which further combustion emanates. Probably darkly glowing clouds might be observed agglomerating and growing in intensity and size with an increasing acceleration until full combustion of the gas present is accomplished. This simultaneous combustion at the beginning should be considered as a slow pressure-rise in comparison with " true detonation," but ultimately it may have the same character.

Assuming " true detonation " to be an explosive combustion progressing with the speed of sound (about 2,000 ft. per sec. at the given temperature conditions), a detonating combustion in a petrol engine running at 1,000 r.p.m. would be accomplished in about 0.0001 sec. or less; but complete combustion

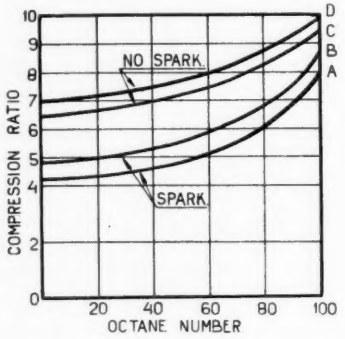

FIG. 9.

Curves of equal knock intensity with and without spark.

within 0.001 sec. (that is, 6 deg. of the crankshaft) might already have caused a heavy knock! Moreover, a sound wave in the charge, as might be expected with detonation, would have more than 5,000 oscillations per sec., which is often far above the frequency of about 1,000 that is observed. In a badly knocking big Diesel engine it was possible, but not without difficulty, to distinguish a slight occasional rather high-pitched sound, which was attributed to a sound wave in the charge—the main knock itself was the well-known heavy blow.

Thus it appears that what is particularly called detonation is actually very often nothing else than some vibration of engine parts caused by rapid change of pressure and should be called knock or bumpy running. On the other hand, there is no doubt about high compression causing a real knock in a petrol engine without spark ignition. Running a variable-compression engine (the C.F.R. engine) at extreme compression-ratio, but strongly throttled, so as to have no knock with spark ignition, the authors managed to switch off spark ignition and open the throttle fully at the same moment, thus making absolutely sure of high compression without hot spots acting as sparks in the combustion chamber; the result was a knock of practically the same noise as caused with spark ignition.

It was possible to determine in this way octane figures for different petrols. Fig. 9 shows curves of constant knock intensity in co-ordinates of octane number and compression-ration. Curve A represents light knock with spark ignition; curve B heavy knock with spark ignition; curve C incipient occasional knock without spark ignition; and curve D regular knock without spark ignition. This method may be used to determine octane numbers. It is less accurate, but much

quicker than the standard method, and from some scientific points of view its results are equally interesting.

The assertion that practically the same knock is heard when running the C.F.R. engine with and without the spark is not complete. Distinction[7] must be made between "knock" and "pink"; the same knock is heard, but not the same pink, the latter, at least, not with the same intensity. The pink may be distinguished from other noises only under favourable circumstances; in the nomenclature of Ricardo's H.U.C.R. engine, the pink with the spark would be called "heavy continuous," the pink without the spark "slight occasional." In both cases the heavy knock noise is by far preponderant.

Now, the C.F.R. engine may also be equipped with a Diesel outfit. It is interesting to note that in this case practically the same noise is heard as in the test with the C.F.R. petrol engine without the spark. Moreover, in the latter case, the diagrams show a delay of ignition quite comparable with the delay in the Diesel engine.

In the opinion of the authors, the knock is caused in some cases by rapid pressure rise due to a progressing flame front, and in most cases by a simultaneous combustion. With petrol engines this combustion may culminate in a severe detonation, with Diesel engines only in a slight occasional detonation; *the knock in both cases is practically of the same intensity, and the pink of different intensity.* This makes it probable that the pink corresponds to some kind of detonation which has a more local character of pressure-rise; it strikes the walls very much like the hammer strikes a bell, and it strikes the charge, setting it "hallooing," the combined result being the pink. Local forces and temperatures, as betrayed by the pink, may be extremely high and cause serious trouble, especially in petrol engines; in this respect the Diesel engine is better off.

The simultaneous combustion as caused by compression has two phases; the first is that of ignition, where chemical processes start without the development of much heat; they lead to the second phase, which starts by simultaneous "flaming" and which may ultimately have a character of detonation. This "flaming," of course, is more rapid than the combustion that occurs in petrol engines in the progressing flame, but otherwise it is very similar.

Tentatively, Fig. 10*a* shows different modes of combustion in petrol engines, especially with regard to the end gas. Schematically the influence of delay[8] and combustion in the end gas are represented at constant speed of the progressing flame (which, of course, does not occur practically). Thus in petrol engines two combustion processes take place side by side: (1) The progressing flame as started by a spark and showing a delay and flame period (Ricardo). (2) The simultaneous combustion (ending as started), mainly by "flame compression," and showing also a delay and flame period, which, however, are different from the first mentioned.

Care must be taken in considering compression beyond the auto-ignition temperature as sufficient explanation for the phenomenon of simultaneous combustion, since there are most certainly some factors besides compression which may shorten the delay, *i.e.*, accelerate the ignition of the primary gas in the Diesel engine and of the end gas in the petrol engine; some of them will also accelerate combustion. They might be called "accelerators." The delay being of great importance, not only in Diesel engines, but also in petrol engines, it will be clear that as a rule these accelerating factors will improve conditions in Diesel engines, but spoil conditions in petrol engines. It will also be clear that accelerating factors which shorten delay, *i.e.*, improve ignition, may have often practically no influence on the speed of the flame front, and *vice versa*.

The accelerating factors may have a more physical or a more chemical character.

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[7] See Appendix.
[8] See Appendix.

Physical Accelerating Factors

(1) *Mixture.*

The influence of good mixture will not be discussed at length, but it may be stated here that it is more effective as an accelerator of combustion than of ignition; an over rich mixture may promote first reaction but hamper final combustion.

(2) *Temperature.*

Neither will be discussed the rather evident effect of temperature, promoting both ignition and combustion. Highest temperature would be quite advisable for Diesel engines, but for a few important, secondary disadvantages, as, for instance, the bad volumetric efficiency.

(3) *Pressure.*

Fig. 10 shows a series of throttled Diesel diagrams, all taken on the same fuel and under the same engine conditions. It is seen that the delay increases

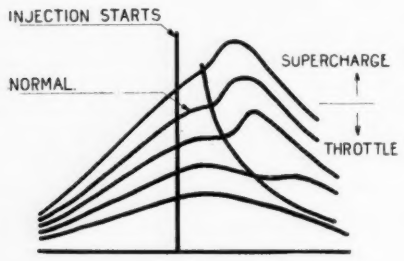

FIG. 10*a*.

Modes of combustion in petrol engines.

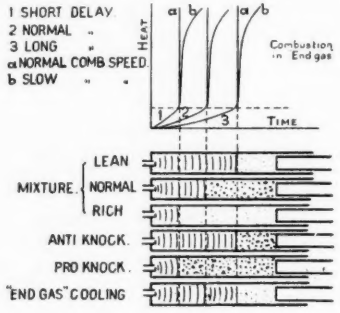

FIG. 10*b*.

Influence of air pressure on delay.

considerably with throttling; at the same time it causes heavy knocking. Now, it should be well understood that in this case the initial and final temperatures of compression remain practically the same; pressure is decreased, not temperature. Temperature would be increased if it was a case of expansion instead of throttling. As a matter of fact, throttling caused just a slightly higher temperature owing to the bigger quantity of residual gas, exhaust being less complete. Temperature fall not being the reason of increasing delay, there is a good reason to suspect the pressure fall itself, at least partly. Supercharging the engine, the reverse of throttling, although not increasing the temperature either, shows the phenomenon in reversed form; increase of pressure shortens delay.

At first sight it might be expected that the rate of heating the fuel as ruled by pressure is of preponderant influence on the delay, but a closer study of the phenomena makes it very probable that by far the most important factor is the oxygen concentration. In petrol engines there is no question of "heating the fuel" as there is in Diesel engines, and yet very much the same influence of pressure is found; other conditions being equal, the charge with the higher initial pressure will show heavier detonation, which is caused, at least partly, by the increased concentration of oxygen. The reason why in Diesel engines the transmission of heat to the fuel, which seems of primary importance actually is of secondary importance in comparison with the concentration of oxygen, will be considered later on. On the whole, pressure is an accelerating factor, both of combustion and of ignition.

(4) *Spark Setting and Injection Timing.*

Some influence of spark setting (Fig. 8) in petrol engines has already been described. In Diesel engines the influence of varied injection timing is somewhat comparable. With retarded injection, the delay will increase by lack of temperature and pressure. With earlier injection the delay first decreases, but then again increases. As an accelerating factor it is of not much importance within practical limits.

(5) *Swirl and Turbulence.*

The different movements of the charge are mostly accelerators; although narrowly related to each other they may have fundamentally different effects on combustion. As to swirls in engines, they may be distinguished according to their origin, shape, type and function. According to origin may be distinguished particularly those formed at the intake through vanes or deflectors at the valve; those formed at the end of compression (the gas being chased in peculiar forms of the engine head); and those formed by flame movement during combustion. According to their shape may be noted the length; the radius; the rotation speed and the translation speed. According to the type, may be found the type of a general uniflow swirl, or the type of a more local swirl with big radius and slow speed of rotation, or the type of a local swirl with small radius and high speed of rotation, or that of local turbulence or that of a streaming turbulence, etc. Turbulence may be considered as an unco-ordinated agglomeration of extremely small and rapid swirls or as woven threads of gas. Analysing these movements of the charge now, according to their function, which is most important, it is found that fundamental distinction should be made mainly among:—

(1) A mixing effect,
(2) a combustion effect (accelerating or retarding),
and (3) a wall effect (cooling or heating).

It is quite interesting to analyse the movements of the charge in different engine types according to these functions. It shows that many movements are advantageous in one aspect and disadvantageous in another. For instance, in one and the same engine a strong swirl may have a good mixing effect but a bad wall effect (cooling); in one engine it may have a good combustion effect, in another engine a bad one, causing, for instance, bumpy running; in a petrol engine it may be an anti-knock as it whirls away the end gas; in a Diesel engine it may be a pro-knock (in an extreme case), as it might whirl away a flame formation.

All kinds of combinations of good and bad effects will occur. It would lead too far here to go into details of one particular case; suffice it to point out that an accelerator may have one effect in one case and the reverse effect in another, therefore each case requires special analysis.

(6) *Vibration.*

There is a typical resemblance between the movement of the charge when in turbulence and when vibrating; in both cases there is a mixing effect. At first it might be thought that alternating important pressure-rises and falls are causing the extremely rapid combustion; but a closer study of the problems shows that this should not be expected to be of such primary importance in practical engine conditions. It occurs in a long tube, as is well known; a test of Dr. H. Nielsen,[9] of Professor Nägel's laboratory in Dresden is quite instructive in this respect. Dr. Nielsen ignited a charge in a tube at one end and could show by means of a piezo-electric indicator and oscillograph readings that a sound wave was set up when the progressing flame had reached the middle of the tube. This

[9] Thesis University, Dresden, January, 1933.

wave then caused an extremely rapid pressure-rise (detonation), which was recorded, as well as the vibrations of the wave, which were found to correlate with the sound heard. Dr. Nielsen then placed a sound-absorbing disk at the end of the tube, with the result that not only was no detonation heard, but also no extremely rapid pressure-rise was recorded as before. The former case might be called that of a " pre-detonation wave." Supposing, however, that for some reason this pre-detonation wave did not occur, it is rather evident that a slightly higher compression would have induced simultaneous combustion, which might have set up a " post-detonation " wave.

As a rule there will be a " post-detonation " wave, but there may also be a pre-detonation wave caused by a " roaring " flame front, and these two will be difficult to distinguish. Moreover, a local explosion, causing extremely high local pressures and temperatures, will knock the wall and the charge and show an effect of pressure-drop somewhat like that of water rushing down when a dam collapses. This phenomenon is well illustrated by the work of Mr. Max Serruys,[10] who succeeded in obtaining diagrams with a maximum pressure indicator of the type shown in Fig. 3. He could prove the existence of local pressures attaining to about 100 atmospheres, while mean pressures were quite normal.

This shows the danger of using indicators in cases where the indicator orifice may be near to a detonating centre, but it illustrates also the danger of local detonation for the engine!

The authors have come to the conclusion that simultaneous combustion[11] will often lead to an explosive combustion, which may be called detonation, and which may cause as well a small overall pressure rise, as, more locally, an extreme pressure rise, giving a knock on the walls, and setting walls and charge in vibration. A pink thus may emanate both from the charge and from the walls. Vibration of engine parts having been started, too, may then be heard as knock or bumpy running. These vibrations might be called " post detonation " waves. A pink in the charge might have been started also by a " roaring " flame front, and in that case it may to some extent have had the effect of an accelerator (by a mixing and " singing flame " effect). This should *not be considered as essential for the rapid pressure rise*, but more as an accompanying phenomenon; nevertheless, this vibration might be called a " pre-detonation " wave. Generally, the pink will have a more local character, accompanied by high local pressures and temperatures, and, as such, knock in a petrol engine, being accompanied by heavier pinking, is more objectionable than knock in a Diesel engine.

Now, in the test without spark in the C.F.R. petrol engine, a sharp knock could be recorded by the bouncing pin method practically without pinking. In this respect it is interesting to note that most petrol-testing engines, like the " Series 30 " engine and the C.F.R. engine, are *really knock testers, not pink testers*, the pink being often non-audible. The original Ricardo H.U.C.R. engine could be used as a " pink tester."

Chemical Accelerating Factors

What can now be said of the chemical causes of detonation? It seems probable that, although oxidation takes place wherever hydro-carbons and oxygen exist together, the speed of reaction under the conditions at the end of the compression is still relatively very small. Therefore it seems that the real combustion will not take place before the temperature has risen so much (owing to oxidation in some particularly favourable region) that the speed of reaction has very considerably increased. The real combustion then spreads with extreme rapidity over the charge present in the cylinder, namely, throughout all that has been so far injected in the Diesel engine and over the remaining end gas in the petrol engine.

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[10] See Comptes Rendus. Vol. 195, p. 1228.
[11] See Appendix

To give an indication of the time-scale involved, in order to get the right impression of these phenomena, it is essential to recall that the time of delay is of the order of 0.001 sec., while the time of combustion, *i.e.*, the time in which, say, 90 per cent. of the available charge ignites and reacts, is often about one-tenth of that time, which indicates that the ignition must proceed with about the velocity of sound.

Now, from a general chemical point of view, it is known that to speed a reaction a hundredfold it is only necessary to raise the temperature by something of the order of 100 deg. C. It is therefore not astonishing that when in one region only the combustion has created sufficient heat to reach the temperature range of measurable combustion speeds, the reaction will spread with great velocity, since the whole charge is already pre-heated almost to that critical temperature range.

These considerations will thus make clear that it is not at all necessary to make any distinction between the reaction during the time of delay and the self-ignition proper. An attempt will therefore be made to get some further knowledge of what happens during the time of delay. This method of approach has the advantage of the relatively simpler conditions during that period, because the reaction speed is still so low that the reaction can be considered to be governed only by temperature. (This may be assumed since the concentration of the reagents can be taken as constant, no appreciable amounts being consumed during the period.)

The initial temperature at which the reaction starts is given by the critical compression-ratio, the ratio C_p/C_v, the temperature at the beginning of the stroke and the heat losses. As has been seen, this critical compression-ratio is about the same for the end gas in the petrol engine and the charge in the Diesel engine, and amounts from 9:1 to 10:1, which means a temperature of, say 550° to 700°C., depending on which ratio C_p/C_v and which initial temperature is assumed. It is very regrettable that no more accurate temperature determinations of the gas mixture after this critical compression are available, as even slight variations of temperature will cause great variations in reaction speed, as explained above.

The difficulties, of course, are due to the fact that this temperature only exists for such a short time; the flame starting within 0.001 sec., it is impossible to measure the real gas temperature with normal instruments. Two methods seem hopeful, however, and the authors anticipate trying them out in due course. The first is the measurement of the actual air density in a Diesel engine at the critical moment, by measuring the electrical breakdown voltage of a spark gap and calculating the gas temperature from this density and the known pressure. The second one, which requires very elaborate apparatus, however, is to measure the intensities of the absorption bands in the ultra-violet portion of the spectrum, and to calculate from these the gas temperature.

Active Oxygen

What can now be said of the reaction between hydro-carbon molecules and oxygen at that temperature? It is obvious that the chance for a reaction must be still extremely small, as at a temperature of 600°C. and compression-ratio of 9:1, any hydro-carbon molecule collides more than one million times every 0.0001 sec. against oxygen molecules, and still less than 1 per cent. has reacted in this time.

The reacting substances, as the chemists say, need to become "activated," and it is only the activated molecules that react. Indeed, when substances which create active oxygen, such as ozone, nitrogen peroxide, ethyl nitrate, and peroxides such as acetone peroxide and tetraline peroxide, are added, the time of

delay is very considerably shortened, indicating a very much greater reaction speed. The influence of tetraline peroxide is, for instance, shown in Fig. 11.

This, however, obviously does not necessarily lead to the conclusion that peroxides or similar compounds are an essential intermediate in the reaction, and that their formation is a prime cause of knock.

Take, for instance, pure tetraline. Its behaviour in a Diesel engine is very unsatisfactory, since there is a very long delay period, notwithstanding the fact that tetraline forms tetraline peroxide very readily in contact with air and that amounts of even a few tenths of a per cent. of tetraline peroxide will shorten the delay period considerably. From the behaviour of peroxides it rather follows that they are unstable in the temperature range considered, so that they will not be formed during the delay period, but that when they are present at that time they will speed up the reaction.

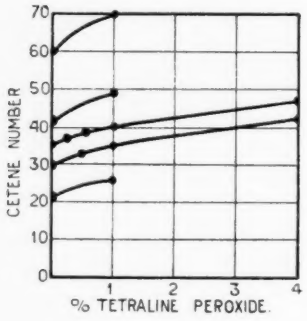

FIG. 11.

Influence of tetraline peroxide on the cetene number of different fuels.

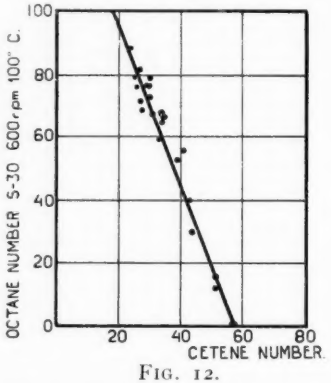

FIG. 12.

Octane number S-30 engine versus cetene number Thomassen engine.

In a Diesel engine where the fuel is injected and brought to a high temperature in a very short time, the formation of peroxides or the like is consequently highly improbable; in the petrol engine they might be formed during the compression stroke, and one simple manner of determining this is to compare the behaviour of the fuel in a highly-compressed petrol engine without spark, with that in a Diesel engine.

It is already known from the publications of Dumanois[12] that there exists a striking correlation between the ignition quality of a fuel in a petrol engine as expressed by its heptane number (being 100 minus the octane number) and its quality in a Diesel engine as expressed by its Cetene number, see Fig. 12. (The Cetene number is the volumetric percentage of cetene in a blend of cetene with α-methylnaphthalene which shows the same delay as the fuel.)

The authors extended these experiments to measurements of the delay in a petrol engine without a spark, and the excellent agreement found up to now between the cetene figures calculated from octane numbers measured in a petrol engine, and the actual measured cetene numbers in a Diesel engine, allows it to be assumed that the *influence of the products formed from the hydro-carbons during the compression stroke of the engine is probably less than has often been estimated.* In this respect the work of Rassweiler and Withrow[13] also needs attention, as it shows that not before 0.0017 sec. before the knock can oxidation products be detected in the end gas by optical means.

[12] See Comptes Rendus, April 3rd, 1933, p. 1003.
[13] See Industrial and Engineering Chemistry. Vol. XXV., No. 8, p. 923; No. 12, p. 1359.

It must, however, be assumed that active oxygen plays an important *rôle* during the delay period, and that the reaction speed, as far as the oxygen is concerned, is governed by the active oxygen present.

Oxygen Concentration

It is thus clear that increase of the oxygen concentration must increase the reaction speed, and *vice versa*. Ricardo's observations[14] have shown such an influence. In the C.F.R. Diesel research unit the authors varied the oxygen-nitrogen ratio from 12/88 to 33/67 and measured the times of delay. The result is shown in Fig. 13, from which it is seen that the reaction speed is proportional to the oxygen concentration.

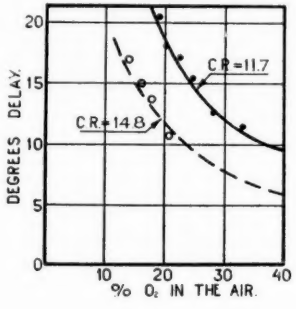

FIG. 13.
Ignition delay as a function of oxygen concentration.

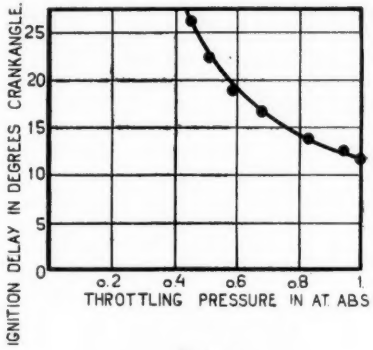

FIG. 14.
Influence of throttling on the ignition delay.

Now, it was stated above that if the pressure of the air in a Diesel engine is increased by supercharging or reduced by throttling (in which cases the temperature after compression is hardly affected) the reaction speed also varies proportionally to the pressure, see Fig. 14. From this the conclusion is drawn that it is not the pressure as such, but the oxygen concentration in mols. per c.c. that is the determining factor. This stresses again the conclusion that the delay in a Diesel engine caused by the fact that the fuel must be warmed up is in all normal cases negligible, compared with the delay caused by the slow reaction speed; so that practically no gain in shortening the delay can be expected from increased heat transfer from air to fuel.

Another conclusion is that the lifetime of the active oxygen is not affected by the presence of the nitrogen.

Active Hydro-carbons

So far the oxygen has been considered and now the other partner in the reaction, the hydro-carbon, needs attention. In the temperature range (550°-700°C.) to be considered it is known that most of the hydro-carbons present in the fuel are not stable, but will crack. It might be suggested, therefore, that perhaps the hydro-carbons themselves do not react with the oxygen, but that only the parts are just split off, or in any case that the thermal stability of a hydro-carbon plays an important *rôle* in its reaction with oxygen in hot air. Indeed, the authors found such an indication in the first years of their Diesel

[14] See Report of Empire Motor Fuels Committee, I.A.E. Proc., Vol. XVIII., Pt. I., 1924, pp. 329-331.

research work, when they found that an empirical formula given by A. Holmes[15] for predicting the suitability of a fuel for the manufacture of gas from its density and boiling range, checked exactly with their curves for predicting its suitability for Diesel fuels from the same data. It may be remarked in passing that these curves were the result of very many trials to relate the ignition delay to some physical or chemical properties of the fuel and that density combined empirically with average boiling point was found to show the best correlation though far from ideal. The idea that the gas formed from a fuel oil has some relation to its quality as a Diesel fuel is already old and dates to P. Rieppel.[16]

The authors therefore made an apparatus for measuring the " initial cracking speed " of a fuel, that is, the cracking speed at a given temperature, and during such a short time that no appreciable amount of the fuel is cracked, cracking speed being then constant. Fig. 15 shows the apparatus. The oil drops regularly

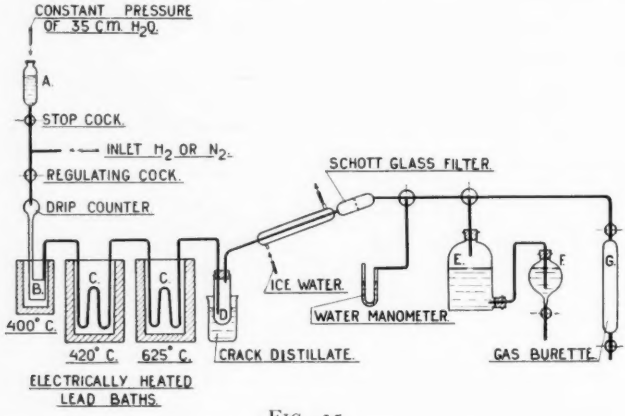

FIG. 15.

Apparatus for the determination of the thermo-stability of hydro-carbons.

in a heated vessel B, in which it is evaporated, then through a thin tube in which the vapour is further heated and cracked, then through a cooler, after which the gases are collected and measured, whilst the liquid flows into another glass flask and is also measured.

First, fractions of narrow boiling range were taken and an attempt was made to find the cracking speed by analysing the reaction products by means of rectification and by measuring the amount of mols. that were formed with boiling points outside the boiling range of the initial product. These early experiments were reported by Dr. Van Dyck at the Symposium of Spontaneous Ignition Temperature, London,[17] after Dr. W. R. Ormandy had drawn attention during the discussion to the possibility of a relationship between quality of an oil for Diesel fuel and its quality for gas making.

Later on the authors adopted the following scheme. First the average molecular weight of the fuel was determined by bringing it into the gaseous state according to the Victor Meyer method by heating it in a boiling mercury bath using pure nitrogen as replacement gas. The fuel was then submitted to the cracking process, after which both from the gas and from the liquid again the average molecular weights were determined; from the gas by combustion and

[15] See Brennstoffchemie, May 1st, 1931, p. 172.
[16] See Forschungsarbeiten Heft 55, 1907-1908.
[17] Organised by the Inst. of Petr. Tech., Feb., 1932.

from the liquid in the Victor Meyer apparatus. From the known quantities and the known average molecular weight it was then possible to readily calculate the amount of mols. newly formed in the cracking process.

It is obvious that the cracking conditions, especially the temperature and the cracking time, had to be kept constant with care and had to be known, for which many separate investigations had to be carried out. The determination of the heat-transfer coefficient in the thin cracking tube, to establish the actual temperature of the gas, gave much trouble. Also the influence, if any, of the material of the tube was determined and therefore tests were carried out with pyrex and two special chromium steels of Krupp NCT_3 and FK345. For their final experiments the authors chose the latter material, which is very resistant to heat and corrosion and does not seem to influence the cracking catalytically. Before

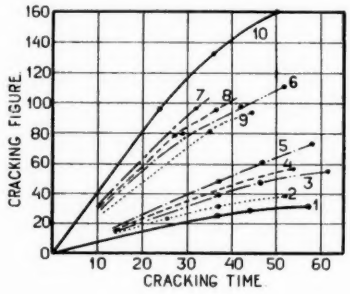

FIG. 16.

Relation between cracking figures and cracking time.

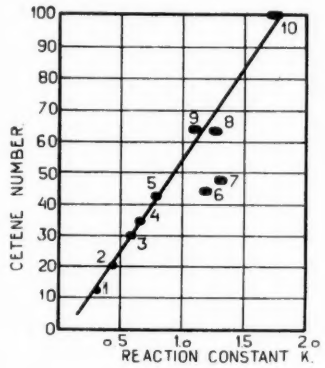

FIG. 17.

Reaction constant K against cetene No. cracking temp. 635°C.

each experiment the tube was carefully cleaned by passing air or oxygen through it, so that all carbon which might have been formed in the previous run was burned out. The apparatus being then filled with oxygen-free nitrogen was ready for operation.

To determine whether tests were carried out in the range of the " initial cracking speed " experiments were made with different cracking times ranging from $\frac{2}{3}$ to $1\frac{1}{3}$ sec. The result is shown in Fig. 16 for a temperature of 635°C., where the amount of newly-formed mols. per unit of weight of the initial oil (cracking figure) is shown against the cracking time in arbitrary units.

From this figure the reaction constant K was derived, as determined by the number of newly-formed mols. per unit of time and per unit of weight of the initial oil. In Fig. 17 this reaction constant is set out against the cetene number for different Diesel fuels. The fuels were so chosen that they cover, not only a wide range of cetene numbers, but also oils of widely varying character. As is shown in Fig. 17, there no doubt exists a correlation between the reaction constant K and cetene number, and seven of the nine fuels examined even show a straight line relationship. Sub-standard zero (No. 1) and sub-standard 100 (No. 9) appear to lie on one line with sub-standard 40 (No. 4) and cetene (No. 10), but two fuels Nos. 6 and 7 definitely do not correlate with the others, as they deviate far more than the probable error from the measurements which are shown in Fig. 17 by the error ellipses around each point. These fuels were carefully checked, but an explanation for their behaviour was not found, since

neither their boiling range nor their other characteristics showed any peculiarity which might throw suspicion on the results.

It might be assumed that the cracking temperature chosen is rather arbitrary and that perhaps at another temperature the relation would become different. The authors therefore changed the cracking temperature, which showed a temperature influence on the cracking speed resulting in a multiplying factor of about 1.3 for every 10 deg. C. for various fuels. The investigation was then extended to the gasoline range. General indications showed that here again the thermal stability of the hydro-carbons plays an important *rôle* in their reaction with oxygen at high temperature. The lower members of the series which are known to be much more stable than the higher ones show the greatest anti-knock value in the petrol engine, and cracked or reformed gasolines, that is, material that has been kept for a very long time (compared with the periods involved in the engine) at a high temperature, generally show better octane numbers and lower cetene numbers than the original material.

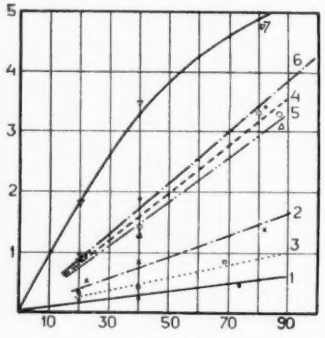

FIG. 18.

Relation between volume of cracked gas and cracking time (same scale of Fig. 16).

As the petrols boil at a far lower temperature than the Diesel fuels a second heater was introduced to warm up the vapours to a known temperature lying below the cracking range, but as near as possible to it, before they entered into the cracking tube proper. Separate experiments showed that at a temperature 400° C. no measurable cracking occurred at the time of pre-heating. It was also found that the temperature influence on the cracking speed of petrols was greater than on the cracking speed of Diesel fuels and amounted to a factor of 1.5 for every 10 deg. C. Different fuels not only differ somewhat in this respect, but sometimes the factor changes markedly with temperature. Fig. 18 shows the influence of time on cracking for different fuels.

From this it will be seen that the observations have been carried out in the range of initial cracking, although it might be advisable to shorten the cracking time still further, which, however, would lead to difficulties of measurement. In Fig. 19 the log. of the reaction constant K is plotted for various petrols against $1/T°$ C. abs. and in Fig. 20 the reaction constant at 625° C. against octane number.

Petrol No. 1 with a high octane number shows a low cracking speed; No. 2 is also low; No. 5 with a low octane number has a high cracking speed and normal heptane No. 6 has a still higher reaction constant. So far, although the ratio of cracking speed at one given temperature does not correlate so well with the octane number as does the cracking speed of Diesel fuels with the cetene number,

there is still a fair correlation. A recent investigation with iso-octane (No. 7), however, showed this substance to have a cracking speed still *higher* than normal heptane, so that it came quite out of the range. As the temperature coefficient showed it to be practically the same as that of normal heptane in the range from 570°-650° C. it is rather improbable that the abnormal behaviour of iso-octane should be ascribed to the fact that cracking was carried out at an unsuitable temperature. Mixtures of iso-octane and normal heptane were then investigated, and it was found that the relation of the gas formation to the composition was as shown in Fig. 21. This figure shows clearly that something abnormal takes place, as the gas formation does not change *pro rata* with the composition, which is to be expected in the range of initial cracking. The authors are now examining whether in this particular case the wall has still a catalytic influence and also

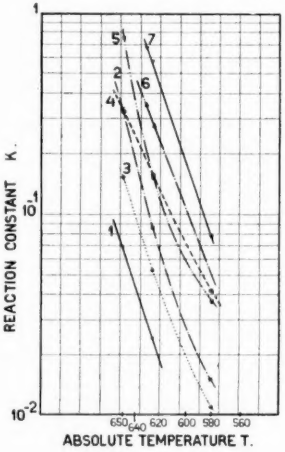

FIG. 19.

Log. K against 1/T.

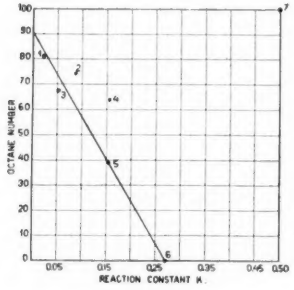

FIG. 20.

Reaction constant K against octane No. cracking temp. 625°C.

whether the cracking speed of the hydro-carbon diluted with an inert gas such as nitrogen, shows a different behaviour from that in the undiluted vapour. So far no explanation has been found for the abnormal behaviour. From a theoretical molecular point of view it would be expected that iso-octane, which is a compact molecule, would be more stable thermally than normal heptane, and it is known from the admirable research work of Lovell, Campbell and Boyd,[18] of General Motors, into the knock tendency of various pure hydro-carbons that the more compact a molecule the higher is its knock rating. There is, however, still another possible view, as obviously it is not sufficient that a hydro-carbon should be thermally unstable to give a quick reaction with oxygen. It is also necessary that the activated molecule, which is either just on the point of decomposition or has already commenced to decompose, should react promptly with oxygen or activated oxygen. Now the theoretical investigations of Heitler and Schuchowitzki[19] have shown that the radical CH_3 requires some electronic activation before it can react, and further that this activation energy decreases for the higher radicals, thus $C_2 H_5$ has a lower activation requirement than CH_3.

[18] See "Industrial and Engineering Chemistry," January, May, 1931. October, 1933.
[19] See Phys-Zeitschrift Sowjet Union Band 3 Heft 3, 1933.

Iso-octane which is formed by hydrogenation of di-isobutylene will most probably split up when it decomposes into iso-butyl which, owing to its very symmetrical structure, might have a fairly stable configuration, of which the structure may perhaps be comparable with that of triphenyl methane, which is one of the known stable radicals. Also, from the experiments of General Motors, it is known that an iso-butyl group in a naphthenic ring shows a far higher knock rating—that is, lower reaction speed—than any other configuration of four carbon atoms on such a ring. The authors, therefore, investigated tetra-isobutylene which was formed by further polymerisation of isobutylene. This substance, which, by the way, has the same formula as cetene, $C_{16}H_{32}$, behaves in a Diesel engine as a very unsatisfactory fuel, and shows a cetene number of only 15, which is about equal to that of iso-octane.

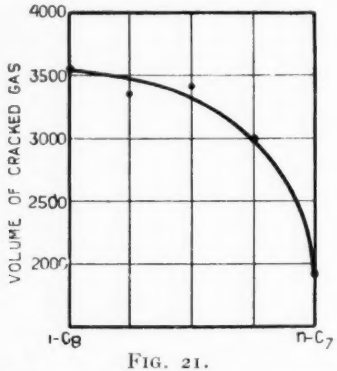

FIG. 21.

Volume of cracked gas for mixtures of iso-octane and normal heptane, cracking temperature 625°C.

When the tetra-isobutylene was subjected to the cracking operation, it, like iso-octane, behaved quite abnormally, also giving great amounts of cracked gas.

It must, therefore, be concluded that low thermal stability is a necessary, but not a sufficient, condition for a high oxidation speed. *Up to now no example has been found of substances with a high thermal stability and high oxidation speed.*

How exactly oxygen reacts with the hydro-carbon or hydro-carbon fragments needs still further research work. Spectroscopic analyses of the absorption bands during cracking, and of the absorption and emission bands during oxidation may lead in this connection to further knowledge. In this respect attention is drawn to the admirable work of F. J. Lauer[20] on the oxidation of methane in oxygen in a flame, in which it is shown that first the methane splits off the radical CH and even forms C=C before reaction starts with oxygen which leads through OH and C=O to the water-gas equilibrium, and to the work of Rassweiler and Withrow, of General Motors, who spectrographically proved that formaldehydehide is formed " in the non-inflamed gases in the knocking zone just prior to knock," *i.e.*, during the delay period of the end gas.

Concentration of Active Hydro-carbons

In any case the concentration of active hydro-carbons must have as important an effect on the velocity of the reaction as that of oxygen.

[20] See Zeitschrift für Physik, Band 82 Heft 3 and 4, 1933. Page 179.

In the petrol engine the influence of mixture strength can be found, but it is not easy to isolate it, due to the large variations in flame compression-ratio that accompanies change of mixture strength. It can, however, be studied by itself by running the engine at high compression-ratios without spark.

In the case of the Diesel engine the fuel vaporises and it has already been seen that the vapour needs only a negligible time to reach the temperature of the air. Now, in contrast with the petrol engine, the vapour concentrations in a Diesel engine vary from very high near the liquid surface, to very low at points far from the fuel particles. However, the regions of non-homogeneity in the mixture are so small in dimensions that in the time considered each agglomeration must be regarded thermally as a whole. Therefore, only the average space concentration of the fuel vapour determines the heat produced per unit of time and the increase in temperature.

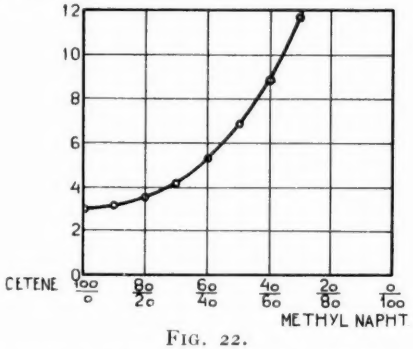

FIG. 22.

Ignition delay of cetene—I. methylnaphthalene blends.

Now, only in extreme cases of very high boiling hydro-carbons with boiling points between, say 400°-500° C., has it been found that the delays are longer than would be expected from the behaviour of the lower boiling substances of the same chemical character. Therefore, it must be concluded that with all normal fuels also the oil is heated up during a period which is short compared with the delay period. Experiments with oils highly pre-heated before injection lead to the same conclusion, since there is practically no difference in delay between cold and hot fuel.

Usually, when the delay is shorter than the injection period, the factors that determine the average concentration are rather complex, so that only from tests under long delay conditions it would appear that the influence of the concentration on the delay can actually be determined. In the discussion after a paper by Messrs. Davies and Giffen,[21] Mr. A. L. Bird gave some explanation of the anomalies in ignition lag measurements founded on differences in fuel concentration. Variation of the excess air ratio from 10:1 to 3:1 changed the delays from 0.016 sec. to 0.004 sec., but further information regarding the actual test conditions would be valuable.

With mixtures of hydro-carbons, the concentration of active hydro-carbons is to a first approximation the sum of the partial concentrations of the various active components.

In an extreme case, a hydro-carbon which can give off active parts at the temperature in question may be blended with one that cannot. The latter constitutes, in fact, what Mr. I. A. J. Duff[22] has so aptly called *a diluent*.

[21] See Diesel Engine Users Association, March 31st, 1931.
[22] See Proc. Inst. of Petr. Tech., November, 1931.

Fig. 22 shows a delay curve made up from cetene and α-methylnaphthalene blends, from which it may be deduced that the delay is very nearly inversely proportional to the amount of cetene in the blend—that is, that the increase of temperature at every moment is proportional to the concentration. This is quite in keeping with the above assumption, as α-methylnaphthalene is quite inert under the conditions of test. Similarly, straight-line relationships between the blends of different hydro-carbons are thus accounted for.

It is seen that many ideas have been embodied in this paper which have been previously dealt with by others, more especially the " irritants " mentioned by Duff, which, however, must be imagined to include highly sensitive and active hydro-carbon molecules or fragments thereof, and not only peroxide-like products.

Summary

The authors have put forward the view that it is correct to look at the phenomena of combustion in Diesel engines and in petrol engines from the same aspect. In both cases the number of collisions of activated reagents is decisive, and self-ignition may be influenced equally by activated oxygen as by activated hydro-carbon. It cannot be overlooked that in the petrol engine unstable peroxide-like compounds formed early during the compression stroke may have some influence; their effect will at most produce an effect on the main phenomenon of auto-ignition of the end gas under Diesel conditions. " Detonation " or " pink " may occur in any class of engine, and is a vibration in the air charge due to a local rapid pressure-rise. As such it is most commonly met in a pinking petrol engine, but it occurs also in Diesel engines. On the other hand, " knock " indicates mechanical vibration, mainly of walls, due to a rapid pressure-rise, and is inherent to the petrol pink as well as, in many cases, to the Diesel process. The term " bumpy running " may be reserved finally for those cases where heavy engine parts, *i.e.*, crankshaft, are set in vibration.

The authors wish to thank their Directors for kind permission to publish the above information, and to thank their collaborators of the " Proefstation Delft," and the Amsterdam Laboratory for their valuable work and assistance without which it would not have been possible to accomplish this work, and particularly to thank Mr. J. J. Broeze, who has had a very active part in the preparation of this paper.

Appendix

Dr. W. R. Ormandy and Mr. R. Stansfield having asked in the discussion for an explanation of a few expressions used by the authors, the following elucidations are appended to facilitate the reading of the paper:

Simultaneous Combustion (not instantaneous), is the name given to a combustion that is born and grows simultaneously in many places of a highly-compressed mixture; it often ends (not always) in an explosive combustion or detonation. It should be distinguished from the relatively slow " *progressing flame* " combustion.

Detonation is the name *generally* used for an explosive combustion in engines. It causes a noticeable vibration of the charge (" pink "), and usually also of engine parts. In the latter case distinction should be made, according to frequency, between " *pink*," " *knock*," and " *bump*." The name detonation has been used *particularly* for the " pink " in the charge just mentioned. A progressing flame combustion may also cause a " *knock* " or a " *bump*." *Knock* is the name *generally* used for the well-known audible effects of rough combustion in engines, and has been used *particularly* as mentioned above.

Auto-Ignition Temperature: the meaning is: " until auto-ignition occurs in the engine."

Primary Gas is the term applied to that part of the mixture in Diesel engines causing detonation; *End Gas*, that part of the mixture in petrol engines causing detonation, and *Rest Gas* that part of the burnt gas in any engine left in the cylinder after the exhaust.

Flame-Compression Ratio is the term used for compression-ratio of the end gas before its "flaming," and includes as such the effect of piston compression and flame compression.

The *delay* in the end gas begins theoretically with the beginning of the compression stroke; practically, however, it begins at the moment that the progressing flame starts.

Discussion

Mr. Pye: The authors have made a valuable contribution in enumerating and distinguishing the different types of rapid combustion, and in endeavouring at the same time to correlate the characteristics of combustion in the petrol and the Diesel engine. It has never, he thought, been done before. He must confess that on looking at the paper he came to the conclusion that it was time for some authoritative committee to produce a glossary of the terms to be used in combustion work, to which the harassed engineer might turn for an answer to the riddle, "When is a knock not a pink," or to learn the family relationship between a bump and a thump. He would like later to interpose a few remarks, but he would first ask Dr. Ormandy to open the discussion, and Mr. Stansfield to follow him.

Dr. W. R. Ormandy: Reference is made to "flame compression-ratio," which is stated to be a fictitious conception, but later "flame compression-ratio" is stated as being possibly "twice the piston compression-ratio." It is difficult to conceive a comparison between two such incommensurable quantities. The words "flame compression" convey some meaning, but why "ratio"?

With regard to Fig. 2*c*, he was not at all clear regarding "end-gas," and the action of flame compression. Looking at the figure, it would appear that the curved rings are in some way acting like a piston and compressing the gas. Is that the intention or does the end-gas explode, owing to the fact that it is compressed to a point when ignition takes place in a lot of places, or is it subjected to a high temperature, or are there sound waves which pass through from the piston top which bring about an increase in temperature? What is the difference between the flame compression and the high speed of the flame front? Does the high speed of the latter mean a speed which is artificially generated by means of turbulence or swirl? What is meant by speeding up the flame when activating the end-gas, is this accomplished by means of turbulence, or how otherwise is it done?

His biggest objection is to the paragraph where the authors introduce the terms *micro-mixture* and *macro-mixture*. A man is a benefactor to humanity who "causes two blades of grass to grow where only one grew before," but this does not hold for the man who introduces new terms into the terminology of science, which is already more than adequately loaded! Why say *micro-mixture* when "degree of atomisation" clearly conveys the meaning intended? It is not atomisation in the strict interpretation of the term, but it has conveyed an adequate picture for many years.

With regard to the following statement: "On the other hand, knock in petrol engines may, of course, be diminished by special means, but these means have certain inherent disadvantages. For instance, knock may be greatly repressed by a strong swirl; the swirl whirls away the end-gas and thus protects it against an excessive compression-ratio of the flame front." What is the excessive compression-ratio of the flame front?

He took it that the spark position figures in Fig. 8 are intended to be degrees of crankshaft revolution. On one page the words " simultaneous combustion " are used, and elsewhere the authors state that this is not *simultaneous* because it begins slowly and grows more rapidly as time goes on. This is difficult to understand, and leads him to agree with Mr. D. R. Pye that papers should be prefaced, similarly to systems of philosophy, with descriptions of what is going to be meant by the words used. At the same time, in no system of philosophy of which he was aware do people stick to this!

On three pages there are three separate comments regarding " true detonation," and he was reminded of a little citation from Lewis Carroll:—

> Humpty Dumpty said, " When I use a word, it means just what I choose it to mean—neither more nor less." " The question is," said Alice, " whether you can make words mean so many different things." " The question is," said Humpty Dumpty, " which is to be Master—that's all." Alice was too much puzzled to say anything, so after a minute Humpty Dumpty began again. " They've a temper, some of them—particularly verbs, they're the proudest—adjectives you can do anything with, but not verbs—however, I can manage the whole lot of them! Impenetrability! That's what I say! "

It is stated that knock is caused by a rapid progressive pressure-rise due to a progressing flame front, and in most cases by a simultaneous combustion. Is " simultaneous combustion " what a great many people designate as " explosion "? It seems there is a great similarity. There is a paragraph which he had tried to paraphrase three times, but with different results each time. It refers to a pre-detonation wave caused by a " roaring " flame front, and also to a post-detonation wave. He would like this explained. Further, the statement with regard to oxygen concentration appears to be an involved method of stating that old friend of chemists, the " law of mass action."

With regard to the remarks concerning gas production, he would ask the authors why a material which cracks easily should be favourable for use in Diesel engines, where one wanted to work with the lowest possible compression-ratio. He raised this matter two years ago in order to emphasise the fact that the gas which is produced is material—methane, ethane, propane—which has very high spontaneous-ignition temperatures compared with the ignition temperatures of the products having a higher molecular weight. He believed that the cracking results in the formation, during the process of cracking, of hydro-carbon bodies with a high carbon-hydrogen ratio, the nucleus of the molecule which has had all its legs and arms, as it were, cut off by the cracking process, and it is the particular ability of these high carbon-hydrogen nuclei to accept oxygen at a lower temperature than the gases with which they are surrounded. This enables them to act as nuclei in spreading combustion, in spite of the fact that a considerable amount of material is produced during cracking with very high spontaneous-ignition temperatures.

Regarding the end-gas which remains in the cylinder, and which explodes or detonates, as the term is commonly used, he did not think it is due entirely to the heat brought about by compression, but rather to the activation of the oxygen and of the hydro-carbons by means of radiation produced by the gases which are burning behind the end-gas. Very useful results might be obtained by taking the absorption spectrum of a mixture of hydro-carbon and air, kept at a temperature as near as possible to the spontaneous-ignition temperature of the mixture, in order to determine from the absorption bands what wave lengths are involved in carrying the energy for the electronic activation, both of the oxygen and of the hydro-carbon.

Almost exactly ten years ago, the Empire Motor Fuel Committee published an account of the work of Ricardo and others, which brought up to date at that

time the subject of compression-ratios, and their relation to the nature of the fuel. The matter is of such importance, however, and involves such complicated study that he thought the time was now come when it should be reconsidered and brought up to date, not by one person, but by a committee, and he would venture to suggest that there should be a reference, not only to the work of F. J. Lauer on the oxidation of methane, but also to that of the Dixon school on the subject of combustion in general.

Mr. R. STANSFIELD: The authors have developed the view which Dr. Van Dyck supported at the Institution of Petroleum Technologists in 1932 and show that for some fuels the cracking reaction constants plot linearly with delay or to opposite sign with octane number of petrols. While the reaction constant indicates the thermal instability of the fuel in the presence of oxygen, he suggested there is not sufficient proof, at present, that cracking actually occurs during the delay period in a Diesel engine and, as Dr. Ormandy pointed out, the gases which would form with cracking would have a higher ignition temperature than the material from which they came. It may be, of course, that the residues are sufficiently reactive after cracking for the temperature of ignition to be reduced, but there is experimental evidence that peroxides or other unstable bodies do form during the compression and early combustion stages of a petrol charge. Those who have had to work on the examination of Diesel fuels for ignition quality and also anti-knock value for petrols have realised for a long time that there must be some common causes underlying the two sets of phenomena in most cases, and since there is definite experimental evidence of peroxide formation and that it is a probable cause of knock in petrol engines, he thought it was reasonable to assume that the same thing may lead to short delay in Diesel engines. Whether cracking or peroxidation be the cause of knock and of short delay, there are obviously other unexplained causes, and if a distorted interpretation of the paper is to be avoided it may be worth placing more emphasis on the exceptions in the summary.

Regarding these exceptions, he would like to ask the authors if they have determined the reaction constants for primary Diesel standards, because only secondaries are mentioned in Fig. 17. He thought that the constants for these secondaries fell on the straight line, 1 to 4. Have the constants also been determined, for, say, 60 cetene fuel in Fig. 11 and for the same fuel with 1 per cent. tetraline peroxide? It does not seem at all likely that the 1 per cent. addition of tetraline peroxide will alter the reaction constant, but it certainly has a very marked effect on the delay time.

An argument is built up on the basis of auto-ignition temperatures, presumably those measured in some form of laboratory apparatus such as the Moore, the Jentsch or the Farnborough adiabatic-compression machine. He thought they should stop using the term "auto-ignition temperature" in connection with engine behaviour, unless it is used with the factor of time. From that point of view he would like to re-word the paragraph in this way: ". . . to avoid knock in the Diesel engine, compression must be taken *precisely* to the temperature and the oxygen concentration which gives auto-ignition in the short delay time permissible . . . ," with a similar suitable alteration for the petrol engine example.

It is, of course, not possible to measure the appropriate ignition temperatures directly, but only indirectly in terms of delay or knock, and much confusion would be avoided if we eliminated references to auto-ignition temperatures determined under conditions which cannot apply to engines.

He was surprised to read that "a small amount of detonation should be considered as not undesirable in a petrol engine." It is true that the H.U.C.R. of a given fuel is found by raising the compression-ratio until the power output ceases to increase. At that point a slight knock is heard and any further increase of compression-ratio is accompanied by power drop. But if a smooth running

fuel is then substituted, there is a small but definite power rise to the smooth running curve connecting compression-ratio with output. The difference is too small to be of practical importance in many cases, but at what engine speed at full load should this slight knock be heard and where has the necessary allowance gone for carbon formation and other uncontrollable changes? It may be, of course, that this illustration has been introduced more to give a petrol parallel to the alleged dangers of too short a delay Diesel fuel, than because it is really valid. In any case, both the desirability of a slight full-load petrol knock and the risks of too short a delay fuel seem to me to be entirely imaginary.

As regards the example of the Ford car which was cleared of carbon by running on a heavily detonating fuel, he would like to suggest that the effect was purely one of temperature. The heavy detonation increased the temperature above the normal full load running temperature and burned the carbon away. The authors will be aware that the C.F.R. engine, which runs continuously with moderate to heavy knock, shows a carbon formation above the piston which steadily increases with time, and there is no evidence that it is less in the zone where the most pronounced knock is likely to occur. An inspection of the C.F.R. piston after prolonged running indicates rather that the carbon build-up is greatest where the inlet air keeps the piston cool and least where the exhaust outflow keeps it hottest, and it is not at all related to the flame path between the sparking plug and the bouncing pin recess, where the maximum knock shock seems most likely to be developed. There is no evidence that the carbon is cleaned away by the heavy detonation in that engine.

In discussing the nature of Diesel sounds, the authors mention the vibration of walls and moving parts including the piston and connecting-rod. An interesting example which confirms the view that much of the noise is from mechanical vibration rather than from direct gas vibration, and is due to the general movement of the engine structure, is given by comparing a single-cylinder and a multi-cylinder high-speed Diesel engine of the direct-injection type and of identical combustion chamber, piston and connecting-rod design. The single-cylinder engine is found to knock with a heavy thud while the same type of multi-cylinder engine runs remarkably quietly due to its stiffer general construction and greater mass, any knock being of much higher frequency and lower intensity.

The existence of local gas effects in Diesel engines mentioned as similar to pinking in petrol engines is probably the cause of the scattered high pressure stray points which are observable in Farnborough diagrams taken with long delay fuels in certain engines. Similar stray points show in diagrams taken from pinking petrol engines, but not from either smooth running petrol engines or from Diesel engines using short delay fuels. This confirms the view of the existence of the local rapid pressure rise effects in certain cases.

The authors occasionally seem to have been tempted to examine in detail a definite engine type, but have always resisted the temptation. While he appreciated the reasons for these decisions he thought it would help to emphasise the relative importance of the various hypotheses put forward, if an Appendix could be added containing detailed analyses of a few typical engines.

He would like in conclusion to express admiration for the very ingenious use of the C.F.R. engine with the synchronous motor loading, for the determination of Figs. 8 and 9, and to ask if the authors will give an explanation of the rather cryptic statement regarding Fig. 9, in which they say that this method, from some scientific points of view, gives results of equal interest to the usual method.

Mr. D. R. Pye: The authors have spoken of the vibratory characteristic of a true detonation in a petrol engine, and that, he thought, was a point on which they would all agree. The authors refer to the fact that in a Diesel engine, also, the high pitch sound may be attributed to a sound wave in the charge. That is an interesting suggestion, and he hoped the authors would

be able to follow it up by photographing the combustion in a Diesel engine to show the vibratory character of the flame there also. That would be something quite new, and a real addition to knowledge. On this point of the vibratory character of a detonating combustion, the February Journal of the Society of Automotive Engineers, America, contains a description of a new instrument together with some observations which are so relevant to this discussion that he would briefly discuss them.

(Here Mr. Pye showed four slides from a paper by C. F. Taylor in the Journal of the Society of Automotive Engineers, America, February, 1934, page 59.)

The authors say that " pink " may emanate both from the charge and from the walls. That remark is a little confusing, because surely the sound one hears must always have emanated from the walls, after these have been set into vibration by the rapid pressure changes in the charge.

He wished that more had been said on the chemical aspect of the subject, because the factor of greatest practical importance and theoretical interest, perhaps, in this subject of detonation is the behaviour of tetra-ethyl-lead. The authors have set out to describe detonation in terms of pressure fluctuations, and self-ignition temperatures, but no description of detonation can be complete which does not attempt to explain how it is that the presence of tetra-ethyl-lead in a concentration of about 1 in 100,000 can completely alter the character of the chemical reaction which takes place. It seemed to him that any satisfactory discussion of detonation must go a good deal beyond this question of self-ignition temperatures, and must include a study of the chemical reactions before inflammation takes place.

One further point, in air-cooled aero engines it has been shown that a detonating cylinder is capable of communicating to the cylinder walls something like 25 per cent. more heat per min. than the same cylinder at the same speed and at the same power output, when running on a fuel that is not detonating. That is a remarkable fact which he had never seen satisfactorily explained, and he would very much like to know what explanation the authors can offer.

Mr. L. J. Le Mesurier: The views of the authors on petrol and Diesel knock described and illustrated by Figs. 1 and 2 are generally accepted as a true—if primitive—explanation of the phenomena. No apology is needed for describing in this simple and effective manner the different nature of the action in each type of engine.

The authors have introduced the terms *micro-* and *macro-mixtures* to differentiate between fine and coarse atomisation. He found no reason to use these new terms to describe combustion chamber conditions during the injection period. Atomisation, penetration, and distribution are accepted terms which have been in use for the past twenty-five years, and seem adequately to describe the physical condition in the combustion chamber during the injection period.

On the question of delay it will be generally accepted that " delay appears to be decisive for the fierceness of the knock." It is less easy to appreciate a little further on in the paper, why " delay " should cause disadvantages such as are mentioned, viz., high consumption, smoke, smell, etc. The particular conditions causing bad combustion as described by the authors indicate faulty distribution due to excessively fine atomisation and probably insufficient turbulence. It should not, in my opinion, be ascribed to too short delay as, if so, one would anticipate that the difficulties experienced could be overcome by using a " long delay " fuel.

Actually, however, from the symptoms described, the cure would be provided by better distribution effected by change of spray to give more penetration, or by an increase in turbulence to obtain proper mixing of air and fuel.

Under the heading of " Spark Setting and Injection Timing," it is stated that with retarded injection, delay will increase by lack of temperature and

pressure. This is probably a mistake in terms as, with retarded injection at, say, top-dead-centre, the temperature and pressure will be at their maximum and the delay will be a minimum.

Under the heading " Oxygen Concentration," proper emphasis has been given to the fact that it is the oxygen rather than the pressure which determines delay. It is not, however, clear why " practically no gain in shortening delay can be expected from increased heat transfer from heat to fuel." Delay is so clearly linked up with temperature that it is certain any increase in air temperature, and, therefore, of heat transfer, will materially reduce the delay.

The subject of knock in the small high-speed Diesel engine is undoubtedly an important problem, and it is at least satisfactory to find that the general principles involved in reducing knock are becoming well known. There are, however, so many factors to be considered in arriving at the best engine design that it may well be impossible to evolve any type of engine which will function equally well on long or short delay fuel.

It would be interesting to have the authors' views on the possible effects of their research on problems affecting the larger slow-running engines used in marine service. Knock in such engines is more usually a question of mechanical conditions, such as fit of piston, side movements of crossheads, etc., but, nevertheless, the question of " delay " is still probably important, and may also have an influence on the condition of connecting-rod and other bearings, and on the general vibration of the engine.

Mr. R. P. FRASER: The word " detonation " has been used a great deal to-night, but he thought that if the phenomenon associated with initiation of the detonation wave were better understood, and they had a better appreciation of the wave velocities concerned (always above 1,500 metres per sec.), they would agree that the formation of a detonation wave never occurred in an engine.

He had always been doubtful whether an explosive gaseous medium igniting autogenously at many points by the setting up of centres of high energy in the body of the gas, could propagate flame or burn as quickly as it would do under the conditions of a detonation wave passing through it. He therefore thought that the so-called spontaneous ignition of what the authors refer to as the " end-gas " occurs by reason of the passage of a shock wave or intense compression wave generated in the rear of the flame and passing ahead of it. This occurs at a time just after the flame envelope is arrested by the pressure built up ahead of it. This process of " flame arrest " and occurrence of a subsequent shock wave during an explosion is known, and many photographic analyses of such happenings have been obtained.

The longer the vessel and the greater the rate of burning of the medium, the more violent this process of arrest and subsequent compression wave production becomes. The flame, however, quickly accelerates again, and, should the vessel be of greater length than diameter, will eventually proceed to catch up and overtake the compression wave, which is travelling ahead of it. Should the compression wave be of sufficient intensity and the rate of burning of the mixture be sufficiently rapid, a detonation wave will be produced when this overtaking occurs.

This process can only proceed in fast-burning mixtures and vessels of considerable length. In short vessels under engine conditions of temperature and pressure, the production of any such compression wave may, however, cause extremely rapid inflammation of the sensitive partly oxidised and excited gases ahead of the flame front, thereby giving an extremely rapid pressure rise indicative of detonation, but *not* caused by it.

In all explosions in closed vessels, whether ignited by spark or not, compression waves can be discerned in the later stages of the burning, much photographic evidence can be produced to show that these waves are influential in effecting the overall rate of burning, and also that they are hard to destroy. It

is probable that the continued reflection of these waves backwards and forwards within the combustion chamber during the later stages of the relatively slow-burning fuel-air mixtures are responsible for the characteristic pinking noise. It should be remembered that such waves have velocities of the order of 1,000 metres per sec. in the still-burning incandescent gases. This process of reflection is of only secondary importance compared with their effectiveness in the early stages in bringing about the almost spontaneous ignition of the so-called " end-gas."

Considerations of methods to aid in the removal of these waves are, to my mind, of tantamount importance. From our knowledge of the propagation of flame prior to detonation, such method as dividing the flame into more than one envelope and avoiding combustion chamber pockets towards which they may move, and also flat reflecting surfaces, suggest themselves as being helpful in this respect.

He felt sure that for the complete analysis of the progress of an internal-combustion engine explosion, more than the measurement of pressure development and fuel characteristics will be required, and he thought it fair to say that much more light upon the matter will be obtained when the photographic method of explosion analysis is more universally recognised.[23]

Dr. F. B. THOLE: From the chemist's point of view, the most interesting section of the paper is that dealing with what happened to the oxygen and to the fuel during the moment before combustion started. The authors state that " it must be assumed that active oxygen plays an important *rôle*." It is not clear whether they imply that the oxygen in the cylinder during this moment exists in two forms, one highly active and the other normal, or whether the whole of the oxygen is uniformly active. If the assumption is made that some of the oxygen molecules become exceptionally activated (say, by decomposition into atoms) at that temperature, and consequently behave like super-oxygenated compounds, such as ozone or peroxides, it should be quite possible to test this assumption experimentally by withdrawing a sample of the oxygen at that moment and applying chemical tests.

The other view, that it is the hydro-carbon molecules which give rise to super-active nuclei as a result of cracking, seems more plausible, although it appears doubtful at first sight if more than an infinitesimally small proportion of the fuel could be cracked in the short period of time available.

Both the ease of cracking and the direction in which fission of the carbon chain occurs depend very much on the molecular structure which is being cracked, and consequently it is not at all surprising that iso-octane and tetra-isobutylene, for example, behave very differently to other hydro-carbons (cracking in such a way as to produce large volumes of gas), nor that some of the fuels referred to in Fig. 20 (including iso-octane, at point No. 7) do not lie on a smooth curve. It would seem more surprising if they did in view of the variety of their structures.

The detailed analyses of the gases obtained from hydro-carbons which fall on and off this curve would be of interest, as they might indicate different types of fission of the carbon chain.

Mr. W. A. TOOKEY (*communicated*): When considering various points for discussing papers of the type presented by the authors, one wondered whether any change would have been evident in the views expressed if the experience with similar phenomena gained from gas engine research and operation had been theirs. Engineers who have been " through the mill " with engines using town gas, producer gas, coke oven gas, straight water gas and carburetted water gas know much about detonation, early firing, pre-ignition and similar phenomena and how to obviate it in gas engine design and operation.

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[23] *Vide* Fraser, *Journal*, Soc. of Chemical Industry, 1930, Vol. XLIX., No. 8, page 103; and Bone and Fraser, *Phil. Trans.*, Series A, Vol. 228, Part III.

Professor Burstall's experiments on behalf of the Gas Engine Research Committee of the Institution of Mechanical Engineers reported as long ago as 1908 were *inter alia* concerned with similar phenomena, but he used different nomenclature. To-day gas engines are in daily service which, under certain conditions, " bump," " knock " and " pink " in much the same manner as the present authors have described in connection with petrol and Diesel oil fuels. In the liquid fuel engines mainly used for motor vehicles the necessity of trying to get a " quart into a pint pot " naturally rendered them more prone to the phenomena and this seems to be the class with which the authors' work is mainly concerned.

One wonders what benefit a mechanical engineer can obtain from the authors' paper. Will oil fuel remain unchanged so that its composition giving the results shown may be relied upon for the next few years? Can producers of fuel oil give warranties that their different brands will not vary from " standard " by more than certain definite narrow limits?

What will be the probable result of any change in the production processes of fuel oils as far as the mechanical engineer is concerned? Are we to accept the position that changes in the incidence in taxation in all or any parts of the world which may, and no doubt will, influence purchasing contracts can be disregarded by the mechanical engineer? Or will it be necessary for him to continue designing his engines as a compromise, permitting reasonable fuel variations with some loss in efficiency—thermal or industrial—under keenly competitive commercial guarantees?

The paper is an excellent report upon a definite line of investigation from the point of view of the petroleum technologist. But in the writer's opinion its value would have been greatly enhanced if the needs of the mechanical engineer had been more in evidence than appears at a first reading.

Prof. A. C. Egerton (*communicated*): The paper is interesting in that the problem of knock is reviewed in connection both with the petrol and the compression-ignition engine. The point that clearly emerges is that this problem is really a chemical one, which we shall more perfectly understand when we know more of the chemical behaviour of hydro-carbon combustion.

Will the authors state how it is that, when the rate of reaction of oxygen and hydro-carbon at a given temperature is very much greater than the rate of cracking, they consider that cracking determines the likelihood of knock? Is it not rather that those molecules which easily crack are those which are easily attacked by oxygen? He could quite see the point that something must start the particular type of combustion, and the provision of radicals which might be easily oxidised is a possible explanation, but he thought there are a good many reasons for it not to be the essential first step in the process; for one thing, one would think that the addition of easily-dissociated organo-metallic substances would give rise to knock, but even in the case of those which are not anti-knock, he did not think there is much evidence of their acting as pro-knocks. With regard to pro-knocks, he noted that ozone and nitrogen peroxide are cited as substances which give rise to active oxygen, and become pro-knocks. He was wondering whether the ozone survives the compression stroke, and whether either of them *per se* act as pro-knocks. He would be glad to hear the evidence for these statements.

Mr. W. Hamilton Martin (*communicated*): The authors state that detonation, which, they point out, is actually a vibration in the air charge due to a local rapid pressure rise, may occur in any class of engine. It may be of interest to record, however, that with an I.C. engine consuming coal dust, no noticeable detonation occurs. This may, perhaps, be attributed to the fact that the inherent oxygen content of coal dust fuels offers a more readily combustible mixture with the hot air it meets, giving a more complete, though slower, consumption than liquid hydro-carbon fuels, burning more like a slow gunpowder, which results in

a much smoother piston action and a higher mean effective pressure than is even obtainable with a supercharged Diesel engine. Account should, no doubt, be taken of the fact that the solid fuel used in this engine is thoroughly prepared for combustion in a sluice-chamber, and enters the working cylinder as an active combusting gas, so that the delay takes place before the working stroke, in the sluice-chamber.

As soon as this engine is changed over from solid to liquid fuel injection, or even if only a fraction of liquid fuel is added to the solid fuel, detonation commences.

It is possible that research work on a solid fuel engine such as this might be helpful in studying detonation, because the solid fuel burns more slowly than a liquid fuel, and would, therefore, allow more time for observation.

Mr. W. E. Cooper (*communicated*): Do the authors consider that the amounts of the different types of hydro-carbons present in gas oils have any relation to their suitability for Diesel engines, and further, what is their opinion as to the influence of asphalt in fuel oils?

Reply to Discussion

We appreciate Mr. Pye's introductory words and agree that a good glossary of terms regarding combustion in engines will be useful. With a view to distinguishing certain phenomena by special names we reserved the words pink, knock and bump for typical engine noises of different frequencies, as they actually suggest the different sounds, and introduced such names as *end gas, flame compression, simultaneous combustion, post detonation wave,* etc., after having consulted English friends regarding suitable expressions. In answer to questions we have added an Appendix, concerning some of these names.

Dr. Ormandy's twenty-five questions would really take too long to discuss in full, and further the answers are mostly to be found in the text. It is to be regretted that he did not receive the paper in time to study it carefully before the meeting. Dr. Ormandy's first five questions refer to Fig. 2. May we, for reply, point to Mr. Le Mesurier's first remark in this discussion? Dr. Ormandy did not appreciate the word " fictitious," when speaking about the flame compression-ratio, and says: " Flame compression conveys some meaning, but why ratio?" The compression of the end gas due to the combined effect of piston and combustion is very real, and so is the compression-ratio at which the " end gas " is compressed, as expressed physically by the ratio of the densities after and before compression. Compared, however, with the technically defined compression-ratio of an engine (which is not a ratio of densities, but a ratio of volumes), the flame compression-ratio of an engine is a fictitious conception, as there are no real volumes to be compared. We are glad that Dr. Ormandy's greatest objection is to the introduction of the terms *micro-* and *macro-mixture*, and with this we fully agree. It is, of course, a minor point, but it has apparently its importance, since Mr. Le Mesurier, in discussing these terms, says that the authors have introduced the terms *micro-* and *macro-mixtures* to differentiate between fine and coarse atomisation. This statement is wrong or at least not complete, as the two main characteristics are atomisation and distribution, penetration being a quite different matter. To avoid confusion we prefer the two special names for the two main characteristics.

We cannot understand Dr. Ormandy's objection to the notion of simultaneous combustion; obviously he is confusing " simultaneous " with " instantaneous " our definition is to be found in the paper. In our opinion a pre-detonation wave should not be considered essential for detonation in engines, the registered waves being mainly post-detonation waves; this was discussed at length, as detonation in engines is often attributed to a pre-detonation wave in analogy to that which is recorded at explosion tests in long tubes. Dr. Ormandy's

opinion that the effect of " oxygen concentration " is nothing but the effect of the law of mass action is true, but he seems to overlook that in this law some unknown exponents appear, and that therefore our measurements, which prove that the reaction velocity varies in a straight line relation with the oxygen concentration, contribute valuable knowledge to the reaction mechanism. Dr. Ormandy says he believes that the nucleus of a hydro-carbon molecule has a lower spontaneous ignition temperature than its arms and legs. This reminds us of the opinion that the spontaneous ignition temperature of droplets of fuel, being lower than that of the produced gas, causes the ignition in Diesel engines to start at the droplets. Careful experiments have shown, however, that the spontaneous ignition temperature of the produced gas in the nascent state corresponds in the heated-pot test with that found for falling droplets of fuel. Moreover, how would Dr. Ormandy determine which part of a broken molecule (say, normal heptane) corresponds to the body, and which to the arms and legs? As to the influence of the radiation on the self-ignition of the end gas, we may refer to the measurements of Lovell, Campbell and Boyd, mentioned in the paper, which seem to prove that even a close distance of the flame front to the self-igniting end gas revealed no influence on the phenomenon of self-ignition. We entirely agree with Dr. Ormandy's suggestion regarding the studying of the absorption spectrum at a temperature as near as possible to the spontaneous ignition temperature, as we indeed indicated; but we would advise that this be carried out in an engine and not in a heated pot. The authors are perfectly aware of the splendid work done about ten years ago by the Empire Motor Fuel Committee, in which days Ricardo led the way to new and highly important knowledge of engine fuels.

In answer to Mr. Stansfield, if hydro-carbon molecules will crack with a certain reaction velocity at a certain temperature and pressure outside the engine, why should they not do the same inside the engine under the same conditions? As to the amount that will crack during delay period, from our measurements it can be calculated that this will be of the order of a few tenths of 1 per cent., depending on the type of fuel. This amount is of the same order of magnitude as the amount of active reagents (dopes) that are known to have such a great influence on the delay. We agree with Mr. Stansfield that besides cracking, other phenomena might be of primary importance in explaining what happens during the delay period, and it is just to stress this fact that we have pointed to the exceptions, in which high cracking speed did not coincide with high reaction speed. It might be of interest to refer here to a paper by Mr. Rice, entitled " The Thermal Decomposition of Hydro-carbons and Engine Detonation."[24] As to Mr. Stansfield's question whether the reaction constants of primary Diesel standards have been determined, we can say that it was determined for cetene and that it is known that α-methylnaphthaline is very thermally stable, so that they form no exceptions to the rule. The influence of tetraline peroxide on the cracking has not yet been determined, but the influence of tetraethyl lead was found to be nil, measured only in one single experiment at which it failed to show an effect.

We are glad that Mr. Stansfield agrees that it is preferable to stop using the term *auto-ignition temperature* in connection with engine behaviour, unless more data (time, pressure, concentrations) are given. The term was introduced for the purpose of connecting our considerations with the common views in this respect, but the whole paper is an endeavour to do away with this old-fashioned method of representation. The desirability of a slight knock in petrol engines and of too short a delay in Diesel engines arises from the fact that ideal conditions in engines cannot be realised. The better they are, the less the argument holds, and in this we agree with Mr. Stansfield. In the matter of

[24] See *Industrial and Engineering Chemistry*, March, 1934.

cleaning by detonation in petrol engines we, of course, agree that the effect is one of temperature, but then extreme temperature is the direct result of detonation. In this respect Mr. Pye's comments may be considered. The statement regarding Fig. 9 that the no-spark method gives results of equal interest to the usual method, refers simply to the fact that the no-spark method showed itself to be very useful in research work; but, being less accurate, is not to be preferred for routine work.

We agree with Mr. Pye that audible sound must emanate from the walls, but the idea is that the sound resulting from the rapid pressure rise might be created either directly in the charge and be transmitted by the walls, or might be created directly by the walls or by both. There is no reason why in these instances the frequency should be equal, but in many cases, of course, they may be of the same order. Regarding Mr. Pye's question as to why an engine is capable of communicating to the cylinder walls something like 25 per cent. more heat when knocking than when not, our personal view is that this might be explained by the much greater radiation of the knocking zone than of that of the progressing flame, as found in photographic records.

We agree with Mr. Le Mesurier's remark regarding short delay not, as a rule, causing such disadvantages as high consumption, smoke, etc. In certain cases, however, it does and those cases actually can be identified by changing the delay, for instance, by adding a dope, *i.e.*, the difficulties can in large measure actually " be overcome by using a long delay fuel." Mr. Le Mesurier supposes that there is a mistake in terms. This is not so; with too much retarded injection, delay will increase by lack of temperature and pressure, as is clearly shown in diagrams. In the case of injection at dead centre the mean values of temperature and pressure during the delay are not maximal. The question why practically no gain in shortening delay can be expected from increased heat transfer from air to fuel is difficult to explain; but, in our opinion, it is due to the fact that apparently the time required for the chemical process is longer than the time for heating the quantity of fuel necessary for ignition. We cannot agree with Mr. Le Mesurier's suggestion that high ignition quality might also be of great importance in big slow-running Diesel engines; as a matter of fact, these engines are to a great extent not sensitive to low ignition quality.

Mr. Fraser's remarks on detonation are most interesting and will receive our attention in the future.

In answer to Dr. Thole, it is our opinion that all the oxygen does not become uniformly active, but only a very small part of it. Whether this activated state is to be considered as the result of dissociation of oxygen in atoms or that high vibrational or rotational movements or electronic activation or any other form of activation is preponderant must remain open for the moment. We doubt if it will be possible to decide, by applying chemical tests on a sample, which of these alternatives is decisive. As to what happens at the cracking of a hydrocarbon molecule we can say that we actually made gas analyses of the gases produced, but could not find essential differences among the gases from substances that followed the rule and the exceptions. This does not seem surprising, as the difference in the activation of the molecule immediately after decomposition would not show in the stable ultimate gas.

Mr. Tookey asks what benefit the mechanical engineer can derive from the paper. In our opinion a better insight into the phenomenon of combustion is of great use to engine designers. Further, investigations such as are described will enable the oil companies to produce more efficient fuels, which will inevitably influence engine design. No doubt, as Mr. Tookey remarks, it will be necessary for the engineer to continue designing his engine as a compromise, permitting of reasonable fuel variations, at least for the immediate future.

In answer to Mr. Egerton's question as to how it is that the cracking determines the likelihood of knock, when the rate of reaction of oxygen and

hydro-carbon is very much greater than the rate of cracking, we can refer to the experiments of F. J. Lauer, from which it is shown that even in the case of methane, which is one of the most thermally stable hydro-carbons, cracking occurs before oxidation. This points to the possibility that at the high temperatures involved, oxidation goes more slowly than cracking. Although it is quite possible that molecules which easily crack are those that are easily attacked by oxygen, the exceptions mentioned in the paper prove that low thermal stability is, however, not sufficient for high oxidation speed. In these exceptional cases it seems likely that the dissociation products of the hydro-carbons are not active; *vide* also Mr. Rice's paper mentioned above. Regarding the influence of organo-metallic substances, we might remark that even in the case of tetra-ethyl lead great concentrations actually do induce knock, *vide*, *e.g.*, Mr. Duff's paper before the Institution of Petroleum Technologists, May, 1931, in which it is pointed out that the organo-metallic dopes are for themselves substances of low knock value.

Following the communication of Mr. Hamilton Martin, we have no experience of coal dust engines, but we should value the privilege of assisting with some detonation tests in such engines by the addition of some liquid fuel to the coal dust.

Mr. Cooper's question regarding the influence of asphalt is, in our opinion, outside the scope of the paper. We can confirm the fact that the amount of the different types of hydro-carbons play a *rôle* in the suitability of a fuel for Diesel engines. It is clearly shown by the mixture of standard fuels (cetene and α-methylnaphthaline) used for measuring the ignition quality.

SOME DYNAMICAL CHARACTERISTICS OF PROPELLERS

BY

CAPTAIN J. MORRIS, B.A., A.F.R.Ae.S.

1. Referring to Fig. 1, let xOy be the plane of rotation of a rigid rod AOA' consisting of a series of pairs of masses symmetrically disposed about O. Thus

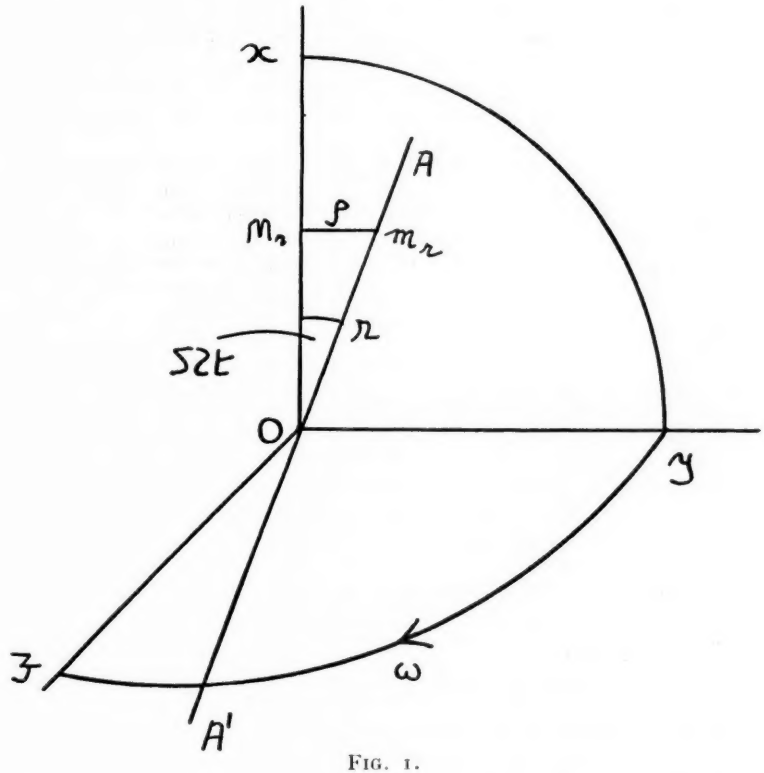

FIG. 1.

at a distance r on either side of O are masses m_r. Let AOA' rotate with uniform angular velocity Ω about the axis Oz and let the plane xOy simultaneously rotate about the axis Ox, supposed fixed in space, with constant angular velocity w. Let ρ be the perpendicular distance m_rM_r of m_r to the axis Ox.

Then the accelerations of m_r are

(i) Along $M_r m_r$

$$d^2\rho/dt^2 - \rho w^2 = -r(\Omega^2 + w^2)\sin \Omega t.$$

(ii) Perpendicular to $M_r m_r$ in the direction Oz

$$(1/\rho)(d/dt)(\rho^2 w) = 2r\Omega w \cos \Omega t.$$

(iii) Perpendicular to $M_r m_r$ in the direction Ox

$$(d^2/dt^2)(r \cos \Omega t) = -r\Omega^2 \cos \Omega t.$$

Hence the inertia couples due to the rotations of the rod will be

(*a*) $\Sigma (m_r/g) \times 2r\Omega w \cos \Omega t \times r \cos \Omega t$

$$= 2(I_o/g)\Omega w \cos^2 \Omega t = (I_o/g)\Omega w (1 + \cos 2\Omega t)$$

about the axis Oy in the direction z to x, where I_o = polar moment of inertia of the complete rod.

(*b*) $\Sigma (m_r/g) \times 2r\Omega w \cos \Omega t \times r \sin \Omega t = (I_o/g)\Omega w \sin 2\Omega t$

about the axis Ox in the direction z to y.

(*c*) $\Sigma (m_r/g) \times r(\Omega^2 + w^2) \sin \Omega t \times r \cos \Omega t$

$$- \Sigma (m_r/g) \times r\Omega^2 \cos \Omega t \times r \sin \Omega t = \tfrac{1}{2}(I_o/g) w^2 \sin 2\Omega t$$

about the axis Oz in the direction x to y.

Clearly (*a*) varies from $2(I_o/g)\Omega w$ when AOA' is along Ox to zero when it is along Oy. Half way between these two positions the inertia couple is $(I_o/g)\Omega w$.

If there were a second rod similar to AOA', fixed at right angles to it at O and rotating in the same plane, then the inertia couple would be a steady one of amount $2(I_o/g)\Omega w$ where I_o refers to one of the rods only.

If the rotation takes place about an axis passing through a point on Oy distant R from O and parallel to Ox, then in addition to the foregoing inertia forces there will be an inertia force on each element m_r of amount

$$(m_r/g) R w^2$$

in the direction $m_r M_r$.

2. If now the body considered consisted of an actual two-bladed propeller of principal moments of inertia A, B, C, in ascending order, then for the position shown in Fig. 1, the angular momenta of the propeller about its principal axes will be respectively

$$(A/g) w \cos \Omega t, \quad -(B/g) w \sin \Omega t, \quad (C/g)\Omega.$$

The angular momentum about the axes Ox, Oy, Oz, will thus be respectively

(i) $(w/g)(A \cos^2 \Omega t + B \sin^2 \Omega t)$.

(ii) $(w/g)(A - B) \sin \Omega t \cos \Omega t$.

(iii) $(C/g)\Omega$.

Hence the rate of change of angular momentum about the axis Ox will be

$$(d/dt)[(w/g)(A \cos^2 \Omega t + B \sin^2 \Omega t)]$$

in the direction y to z.

This will give rise to a gyroscopic couple in the same direction of

$$(\Omega w/g)(A - B) \sin \Omega t \cos \Omega t.$$

The rate of change of angular momentum about the axis Oy will be

$$(d/dt)[(w/g)(A - B) \sin \Omega t \cos \Omega t] - (C/g)\Omega w$$

in the direction z to x; so that the inertia couple in the same direction about Oy will be

$$[C - (A - B) \cos 2\Omega t](\Omega w/g).$$

About the axis Oz the rate of change of angular momentum will be

$$-(w^2/g)(A - B) \sin \Omega t \cos \Omega t$$

in the direction x to y; so that there will be a gyroscopic couple in the same direction of

$$(w^2/2g)\,(A-B)\sin 2\Omega t.$$

If we put $B=A$ we find that the fluctuating portions of these gyroscopic couples become zero. Hence for symmetrical propellers of three or more blades, the gyroscopic couple is steady.

If we put $A=0$, $B=C=I_0$ we find that the results agree with those obtained for the rod.

3. We next deal with the vibration of the blades of propellers which vibration may be considerably affected by the various forcing vibrations to which the blades may be subjected.

The section of a propeller blade is complicated and variable. For the purpose of discussing methods of dealing with the vibration of the blades we will therefore consider the body diagrammatically illustrated in Fig. 2.

Referring to this figure the section of the body in the plane xOy is the upper part of a parabola with its axis along Ox. Its equation will be

$$y=b^{\frac{1}{2}}\,(l-x)^{\frac{1}{2}}$$

where $OB=b^{\frac{1}{2}}l^{\frac{1}{2}}$, $OC=l$.

The face ACA' is the parabola

$$z=a^{\frac{1}{2}}\,(l-x)^{\frac{1}{2}}$$

so that $OA=a^{\frac{1}{2}}l^{\frac{1}{2}}$.

All transverse sections are taken as semi-ellipses with their major axes parallel to AOA'.

Thus at a distance x from O the section is a semi-ellipse whose axes are

$$a^{\frac{1}{2}}\,(l-x),\ b^{\frac{1}{2}}\,(l-x)^{\frac{1}{2}}.$$

The centroids of the sections will clearly lie on the parabola $y=(4b^{\frac{1}{2}}/3\pi)\,(l-x)^{\frac{1}{2}}$. We may, if we choose, assume that the sections are translated parallel to the plane YOZ so that their centroids are arranged on a straight line parallel to Ox.

Assuming that the body is encastre then the equation of motion of an element between two normal sections, one at x from O and the other at $x+dx$ from that point, will be

$$(\partial^2/\partial x^2)\,(EI_x\partial^2 y/\partial x^2)=-(\rho/g)\,A_x\partial^2 y/\partial t^2$$

where A_x = area of section at the point $x=\frac{1}{2}\pi a^{\frac{1}{2}}b^{\frac{1}{2}}\,(l-x)$.

I_x = moment of inertia of this section about a line through its centroid parallel to $Oz=(\pi/8-8/9\pi)\,a^{\frac{1}{2}}b^{3/2}\,(l-x)^2$.

ρ = density of the material.

E = Young's modulus of the material.

Let $y=\gamma\cos kt$ be a solution to the above equation where γ is a function of x only and $k/2\pi$ is a frequency, then

$$\partial^2 y/\partial t^2=-k^2 y.$$

Thus the equation of motion may be written

$$(d^2/dx^2)\,[(l-x)^2\,d^2\gamma/dx^2]=\mu^2\,(l-x)\,\gamma$$

where $\mu^2=\frac{1}{2}\,(\rho/g)\,k^2/E\,(\frac{1}{8}-8/9\pi^2)\,b$.

Let $l-x=\xi$, then the equation becomes

$$(d^2/d\xi^2)\,(\xi^2 d^2\gamma/d\xi^2)=\mu^2\xi\gamma$$

For a solution to this equation we try the series

$$\gamma=a_0+a_1\xi+a_2\xi^2+a_3\xi^3+a_4\xi^4+\ \ldots\ +a_n\xi^n+\ \ldots$$

where a_0, a_1, a_2, $\ldots$ a_n $\ldots$ are constants. On substitution we notice from the resulting identity that

$$n^2\,(n-1)^2\,a_n=\mu^2 a_{n-3}.$$

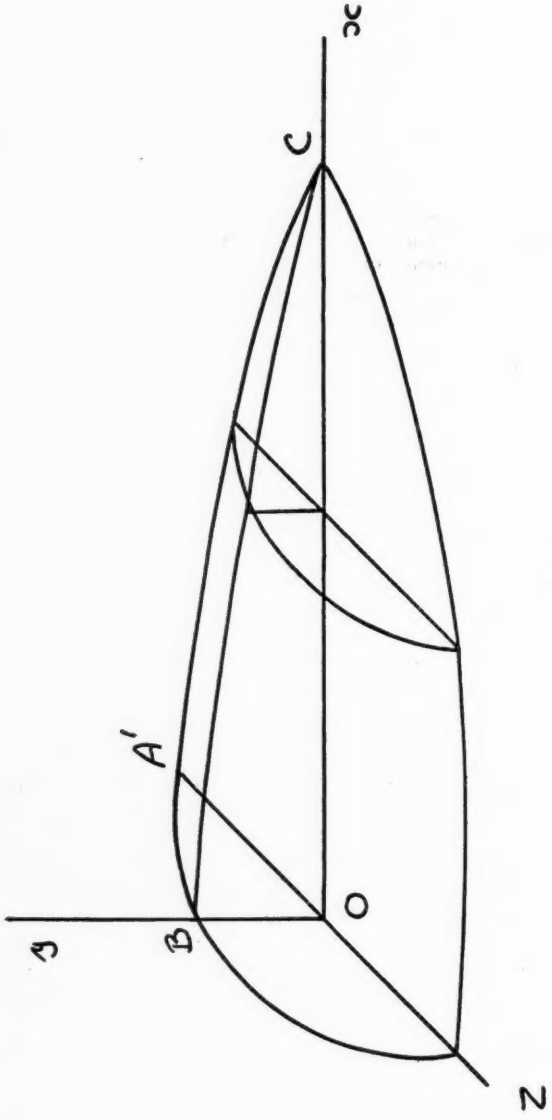

FIG. 2.

Thus the series becomes

$$\gamma = a_0 (1 + \mu^2\xi^3/3^2.2^2 + \mu^4\xi^6/6^2.5^2.3^2.2^2 + \mu^6\xi^9/9^2.8^2.6^2.5^2.3^2.2^2 + \ldots)$$
$$+ a_1 (\xi + \mu^2\xi^4/4^2.3^2 + \mu^4\xi^7/7^2.6^2.4^2.3^2 + \mu^6\xi^{10}/10^2.9^2.7^2.6^2.4^2.3^2 + \ldots).$$

From the end conditions we have

$$x = 0,\ \gamma = 0,\ i.e.,\ \xi = l,\ \gamma = 0.$$
$$x = 0,\ d\gamma/dx = 0,\ i.e.,\ \xi = l,\ d\gamma/d\xi = 0.$$

On making use of these conditions and eliminating a_0, a_1, we obtain the following equation in μ^2 :—

$$(1 + \mu^2l^3/3^2.2^2 + \mu^4l^6/6^2.5^2.3^2.2^2 + \mu^6l^9/9^2.8^2.6^2.5^2.3^2.2^2 + \ldots)$$
$$\times (1 + \mu^2l^3/4.3^2 + \mu^4l^6/7.6^2.4^2.3^2 + \mu^6l^9/10.9^2.7^2.6^2.4^2.3^2 + \ldots)$$
$$- (1 + \mu^2l^3/4^2.3^2 + \mu^4l^6/7^2.6^2.4^2.3^2 + \mu^6l^9/10^2.9^2.7^2.6^2.4^2.3^2 + \ldots)$$
$$\times (\mu^2l^3/3.2^2 + \mu^4l^6/6.5^2.3^2.2^2 + \mu^6l^9/9.8^2.6^2.5^2.3^2.2^2 + \ldots) = 0.$$

The first three terms on the L.H.S. of this equation are found to be

$$1 - \mu^2l^3/36 + \mu^4l^6/35.27.16.$$

Now

$$\mu^2 = \lambda k^2$$

where $\lambda = \frac{1}{2}(\rho/g)/E(\frac{1}{8} - 8/9\pi^2)\,b$.

Hence from the above equation in μ^2 we obtain

$$\Sigma\, 1/k_r^2 = \lambda l^3/36$$
$$\Sigma\, 1/k_r^2k_s^2 = \lambda^2l^6/35.27.16.$$

Hence if $k_1/2\pi$ is the fundamental frequency, a first approximation to k_1^2 will be given by

$$1/k_1^2 = \Sigma\, 1/k_r^2 = \lambda l^3/36.$$

To obtain a second approximation we take

$$1/k_1^2 + 1/k_2^2 = \Sigma\, 1/k_r^2 = \lambda l^3/36$$
$$1/k_1^2k_2^2 = \Sigma\, 1/k_1^2k_2^2 = \lambda^2l^6/35.27.16.$$

Thus

$$(1/k_1^2 - 1/k_2^2)^2 = (\Sigma\, 1/k_r^2)^2 - 4\Sigma\, 1/k_r^2k_s^2$$
$$= (\lambda^2l^6/36^2)\,(1 - 4 \times 36 \times 36/35.27.16)$$
$$= (\lambda^2l^6/36^2) \times (23/35).$$

Thus

$$1/k_1^2 - 1/k_2^2 = (\lambda l^3/36)\sqrt{(23/35)} = (\lambda l^3 \times .81)/36$$
$$\text{so that } 1/k_1^2 = \lambda l^3/40$$
$$\text{and } 1/k_2^2 = \lambda l^3/379.$$

Thus

$$1/k_1^2 = \tfrac{1}{2}(\rho/g)\,l^3/40\,E\,(\tfrac{1}{8} - 8/9\pi^2)\,b$$
$$1/k_2^2 = \tfrac{1}{2}(\rho/g)\,l^3/379\,E\,(\tfrac{1}{8} - 8/9\pi^2)\,b.$$

4. Another method is as follows:—Assume in the first place that the blade has no mass and find the deflection due to unit load at any particular point. Let this point be at a distance d from O, then the equation of flexure at any point x between O and d is

$$EI_x d^2y/dx^2 = d - x$$
$$\text{or } E(\pi/8 - 8/9\pi)\,a^4b^{3/2}\,(l - x)\,d^2y/dx^2 = d - l + l - x.$$

Let $l - x = \xi$ and $E(\pi/8 - 8/9\pi)\,a^4b^{3/2} = 1/e$ say. The flexure equation then becomes

$$d^2y/d\xi^2 = e\,[(d - l)/\xi + 1/\xi].$$

Integrating twice and having regard to the end conditions we obtain

$$y = e\,[(l - d)\,(\log \xi - \xi/l - \log l + 1)$$
$$+ \xi \log \xi - \xi - \xi \log l + l].$$

If the unit load is at the point x, *i.e.*, $d=x$, then we find

$$y_{xx}=e\,[2\xi\,(\log\,\xi-\log\,l)-\xi^2/l+l]$$

where $\xi=l-x$.

The mass of the element of blade at x is

$$m_x=\tfrac{1}{2}\pi\rho a^{\frac{1}{2}}b^{\frac{1}{2}}\,(l-x)\,dx.$$

It may be shown that the summation

$$\Sigma\,(m_x/g)\,y_{xx}=\Sigma\,1/k_r^2.$$

Hence

$$\Sigma\,1/k_r^2=\tfrac{1}{2}\,(\rho/g)\,\pi a^{\frac{1}{2}}b^{\frac{1}{2}}e\int_0^l\xi\,[2\xi\,(\log\,\xi-\log\,l)-\xi^2/l+l]\,d\xi$$

$$=\lambda l^3/36$$

where $\lambda=\tfrac{1}{2}\,(\rho/g)/E\,(\tfrac{1}{8}-8/9\pi^2)\,b$.

This value therefore agrees with the value of the same summation obtained by the previous method.

5. Lord Rayleigh's treatment of the same problem is founded on the fact that a fair approximation to the fundamental frequency is obtained by supposing that the body vibrates in its gravest mode in any reasonable form the body may assume as, for example, the form under its static weight.

The shape of the blade under its own weight is found from the flexure equation

$$(d^2/dx^2)\,(EI_x d^2y/dx^2)=\rho A_x$$

$$=\tfrac{1}{2}\rho\pi a^{\frac{1}{2}}b^{\frac{1}{2}}\,(l-x).$$

Integrating twice and having regard to the end conditions we obtain

$$EI_x d^2y/dx^2=1/12\rho\pi a^{\frac{1}{2}}b^{\frac{1}{2}}\,(l-x)^3.$$

Also

$$I_x=(\pi/8-8/9\pi)\,a^{\frac{1}{2}}b^{3/2}\,(l-x)^2.$$

Hence

$$d^2y/dx^2=(1/12)\;\rho\pi\,(l-x)/(\pi/8-8/9\pi)\,b$$

$$=p\,(l-x)\text{ say.}$$

Integrating twice and having regard to the end conditions we derive

$$y=p\,(lx^2/2-x^3/6).$$

This will be the shape of the blade under its own weight.

At time t in vibration let the shape be

$$y=\eta\,(lx^2/2-x^3/6)$$

where η is a function of t only.

The bending moment strain energy stored up in the blade will be

$$\tfrac{1}{2}\int_0^l EI_x\,(d^2y/dx^2)^2\,dx$$

$$=(1/10)\,(\pi/8-8/9\pi)\,a^{\frac{1}{2}}b^{3/2}l^5\eta^2.$$

The kinetic energy of the blade will be

$$\tfrac{1}{2}\int_0^l(\rho/g)\,A_x y^2 dx$$

$$=(\tfrac{1}{4})\,(\rho/g)\,\pi a^{\frac{1}{2}}b^{\frac{1}{2}}\eta^2\int_0^l(l-x)\,(lx^2/2-x^3/6)^2\,dx$$

$$=(7/5760)\,(\rho/g)\,\pi a^{\frac{1}{2}}b^{\frac{1}{2}}l^8\eta^2.$$

Hence since

$$\text{P.E.}+\text{K.E.}=\text{const.}$$

we find that

$$1/k^2=\lambda l^3/41.1$$

where $\lambda=\tfrac{1}{2}\,(\rho/g)/E\,(\tfrac{1}{8}-8/9\pi^2)\,b$ as before.

This approximation to $1/k_1^2$ is within 3 per cent. of the more exact value previously obtained.

It is to be observed that Lord Rayleigh's method will give a value of k_1 somewhat in excess of its true value.

6. When end loads are present and are taken into account Lord Rayleigh's method is of great convenience.

If, for example, the blade, in addition to vibrating so that its flexural axis remains parallel to the plane zOy, is subject to a rotation about the axis Oy (see Fig. 2), then there is a centrifugal longitudinal force on each element at x of amount

$$(\rho/g)\, A_x x \Omega^2 dx.$$

To obtain the strain energy stored in the blade due to the pulling in of these centrifugal forces we find that the movement of the section at A_x towards O is

$$\tfrac{1}{2}\int_0^x (dy/dx)^2\, dx$$

$$= \tfrac{1}{2}\eta^2 \int_0^x (lx - x^2/2)^2\, dx$$

$$= \tfrac{1}{2}\eta^2\, (l^2x^3/3 - lx^4/4 + x^5/20).$$

Hence the total work done against the centrifugal forces will be

$$\int_0^l \tfrac{1}{2}\, (\rho/g)\, \pi a^{\frac{1}{2}} b^{\frac{1}{2}}\, (l-x) \times x\Omega^2 \times (\eta^2/2)\, (l^2x^2/3 - lx^4/4 + x^5/20)\, dx$$

$$(61/40320)\, (\rho/g)\, \pi a^{\frac{1}{2}} b^{\frac{1}{2}} l^8 \Omega^2 \eta^2.$$

The energy equation now becomes

$$(7/5760)\, (\rho/g)\, \pi a^{\frac{1}{2}} b^{\frac{1}{2}} l^8 \eta^2 + (1/10)\, (\pi/8 - 8/9\pi)\, a^{\frac{1}{2}} b^{3/2} l^5 \eta^2$$
$$+ (61/40320)\, (\rho/g)\, \pi a^{\frac{1}{2}} b^{\frac{1}{2}} l^8 \Omega^2 \eta^2 = \text{const.}$$

from which we find that

$$k^2 = k_0^2 + 61\Omega^2/49$$

where k_0^2 is the value of k^2 when $\Omega = 0$.

Hence $k^2 = k_0^2 + 1.25\, \Omega^2$.

If the blade is offset at a relatively small constant angle α from the axis Ox of the blade, then it may be inferred that approximately

$$k^2 = k_0^2 + 1.25 \cos^2 \alpha \Omega^2.$$

7. Now it may be shown generally that if the centrifugal force acts radially from the neutral axis parallel to OZ instead of parallel to the axis Ox then

$$k_p^2 = k_r^2 + \Omega^2$$

where $k_p/2\pi$ is the frequency when the centrifugal force acts parallel to Ox and $k_r/2\pi$ the frequency when the centrifugal force acts radially from Oz. This difference result is true for all frequencies fundamental and overtones, although the term in Ω^2 in k_p and k_r^2 will not necessarily be the same for all frequencies.

In the particular case considered we have for the fundamentals

$$k_p^2 = k_0^2 + 1.25\, \Omega^2$$
$$k_r^2 = k_0^2 + .25\, \Omega^2.$$

If the blade were of uniform section it may be shown that approximately

$$k_p^2 = k_0^2 + 1.2\, \Omega^2$$
$$k_r^2 = k_0^2 + .2\, \Omega^2.$$

8. We next consider a system as illustrated diagrammatically in Fig. 3.

AOA' are a couple of similar blades fixed at B to a light shaft ON. The system is supposed to be vibrating about ON, N being a node.

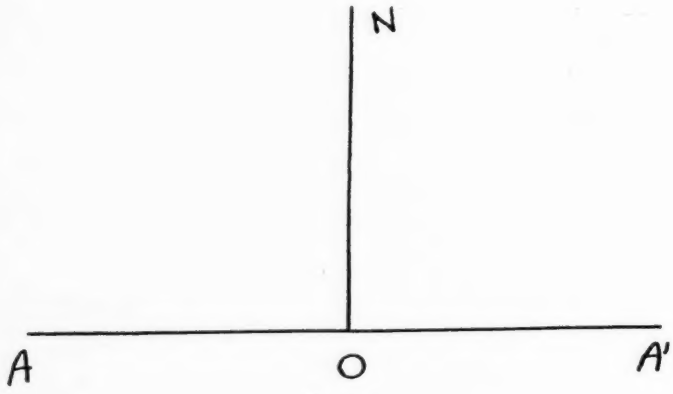

FIG. 3.

Let I_o be the polar moment of inertia of the system about ON and let c be the torsional stiffness of the shaft ON. Then if the blades were rigid the torsional frequency of the system about ON will be given by $k_s^2/2\pi$ where

$$k_s^2 = cg/I_o.$$

If now $k_b/2\pi$ represents the fundamental frequency of either blade about its root at O when rotating in the plane through O perpendicular to ON, then it may be shown that the fundamental frequency of the system is approximately $k_f/2\pi$ where

$$1/k_f^2 = 1/k_s^2 + 1/k_b^2 \quad . \quad . \quad . \quad . \quad . \quad (1)$$

If the system has a mean rotation of angular velocity Ω about ON, then approximately

$$k_b^2 = k_o^2 + .25\,\Omega^2$$

where $k_o/2\pi$ is the frequency of free vibration when $\Omega = 0$.

In addition to the frequencies of the system there will be the frequencies of the blades.

The formula (1) is true whatever the number of blades provided these are all equal.

9. It is to be observed that the separate blade frequency does not arise from the point of view of resonance in the case of forced vibration when the forcing vibrations on each blade are equal and opposite, which will usually be the case of an actual propeller in the torque plane. In the case of fore and aft vibration, however, the forcing vibrations will usually be equal and act in the same direction; consequently resonance between the frequency of such forcing vibration and the frequency of free vibration of the blade may take place.

To prove this for a simple case, consider the system illustrated diagrammatically in Fig. 4.

Referring to this figure, p_1 is a flywheel of polar moment of inertia p_1 about ON which is a shaft of torsional stiffness c to which it is attached. AOA' are a pair of light flexible arms carrying mass m at its end.

Let the system be in torsional vibration about ON. Then if θ_1 is the angular displacement of p_1 at time t; θ_2 the angular displacement of the mean axis of AOA'; γ_1, γ_2, the linear displacements of the masses from this mean axis; L the length of each arm; y_{11} the deflection due to unit load at A or A' for each arm regarded as a cantilever encastre at O; $A_1 \cos w_1 t$, $A_2 \cos w_2 t$ are

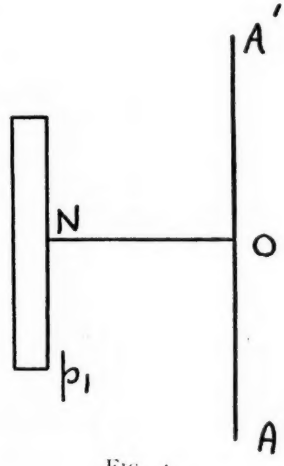

FIG. 4.

forcing vibrations acting on the masses at A, A'; and $P_1 \cos \Omega t$ is a forcing torque vibration acting on p_1, then we have the following equations of motion where g is taken account in p_1 and in m:—

$$p_1\ddot{\theta}_1 = c\,(\theta_2 - \theta_1) + P_1 \cos \Omega t \quad . \quad . \quad . \quad . \quad (1)$$

$$-mL\,(\ddot{\gamma}_1 + L\ddot{\theta}_2) + A_1 L \cos w_1 t$$

$$-mL\,(\ddot{\gamma}_2 + L\ddot{\theta}_2) + A_2 L \cos w_2 t = c\,(\theta_2 - \theta_1) \quad . \quad . \quad . \quad (2)$$

$$\gamma_1 = [\,-my_{11}\,(\ddot{\gamma}_1 + L\ddot{\theta}_2) + A_1 \cos w_1 t\,]\,y_{11} \quad . \quad . \quad . \quad (3)$$

$$\gamma_2 = [\,-my_{11}\,(\ddot{\gamma}_2 + L\ddot{\theta}_2) + A_2 \cos w_2 t\,]\,y_{11} \quad . \quad . \quad . \quad (4)$$

From (2), (3) and (4) we obtain

$$(\gamma_1 + \gamma_2)\,(L/y_{11}) = c\,(\theta_2 - \theta_1) \quad . \quad . \quad . \quad . \quad (5)$$

Also from (3) and (4)

$$(1/y_{11})\,(1 + my_{11}D^2)\,(\gamma_1 - \gamma_2) = A_1 \cos w_1 t - A_2 \cos w_2 t.$$

Thus if $A_1 \cos w_1 t = A_2 \cos w_2 t$ the R.H.S. of this equation becomes zero and

$$\gamma_1 - \gamma_2 = \alpha \cos (k_b t + \epsilon)$$

which is a free vibration of frequency of either arm about its root. This free vibration will therefore be damped out in an actual case.

In these circumstances we find from (3) and (4)

$$(L/y_{11})\,(1 + my_{11}D^2)\,(\gamma_1 + \gamma_2) = -2mL^2\ddot{\theta}_2 + 2AL \cos wt.$$

But by (5)

$$(1 + my_{11}D^2)\,(\gamma_1 + \gamma_2)\,(L/y_{11}) = (1 + my_{11}D^2)\,c\,(\theta_2 - \theta_1).$$

Thus we derive the equation

$$-2mL^2\ddot{\theta}_2 + 2AL \cos wt = (1 + my_{11}D^2)\,c\,(\theta_2 - \theta_1).$$

Also (1) may be written

$$2mL^2\ddot{\theta}_1 - (2mL^2P_1/p_1) \cos \Omega t = 2mL^2c\,(\theta_2 - \theta_1)/p_1.$$

Hence by addition we obtain the equation

$$(2mL^2 + my_{11}c)\,\ddot{\theta}_{12} + (2mL^2c/p_1 + c)\,\theta_{12}$$
$$= 2AL \cos wt - (2mL^2P_1/p) \cos \Omega t$$

where $\theta_{12} = \theta_2 - \theta_1$.

Thus for free vibration of the system

$$1/k^2=(2mL^2/c+my_{11})/(2mL^2/p_1+1).$$

Resonance may take place between the frequency $k/2\pi$ and $w/2\pi$ or $\Omega/2\pi$, the frequencies of the forcing vibrations. But provided $A_1\cos w_1t=A_2\cos w_2t$, no resonance can occur between the arm frequency $k_b/2\pi$ and the frequencies w_1, w_2, Ω of the forcing vibrations.

10. To make allowance for the moment of inertia of the propeller and its flexibility in the torsional vibration of a crankshaft system we may proceed as follows:—

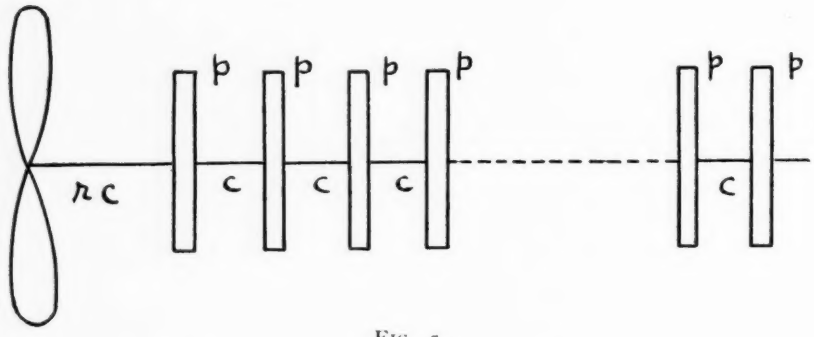

FIG. 5.

Consider a direct driven engine whose crankshaft has n throws.

Let p=polar moment of inertia of each "equivalent flywheel" in which account is taken of g.

c=torsional stiffness of each "equivalent journal."

$c_{12}=rc$=torsional stiffness of portion of crankshaft between the propeller and first throw.

Assume that a node is situated at N and let the torsional stiffness of the crankshaft between the propeller and N be σc and that between N and the first throw $=\rho\sigma c$.

Then $1/\rho+1/\sigma=1/r$.

Let the polar moment of inertia of the propeller be $\rho=sp$.

Then the fundamental frequency of the system to the left of N is given by $k/2\pi$ where

$$1/k^2=sp/\sigma c+1/k_b^2$$
$$=(1/r-1/\rho)(sp/c)+1/k_b^2 \quad . \quad . \quad . \quad . \quad (1)$$

where $k_b/2\pi$ is the frequency of a blade in free vibration about its root in the torque plane. If Ω is the angular velocity of the propeller shaft we have

$$k_b^2=k_o^2+.25\,\Omega^2.$$

The frequencies of the engine system about the node N are given by $k/2\pi$ where

$$k^2=4(c/p)\sin^2\alpha/2$$
$$\text{and } \tan n\alpha\tan\alpha/2=\rho/(2-\rho) \quad . \quad . \quad . \quad . \quad (2)$$

From (1) we have

$$1/4s\sin^2\alpha/2=(1/r-1/\rho)+c/sp\,(k_o^2+.25\,\Omega^2) \quad . \quad . \quad (3)$$

By (2)

$$\cot n\alpha\cot\alpha/2=(2/\rho-1).$$

Hence by the elimination of ρ

$$1/2s \sin^2 \alpha/2 + \cot n\alpha \cot \alpha/2 = (2/r - 1) + 2/sp\ (k_b^2 + .25\ \Omega^2) \quad . \quad (4)$$

or $(1/2s) \operatorname{cosec}^2 \alpha/2 + \cot n\alpha \cot \alpha/2 = (2/r - 1) + 2c/sp\ (k_b^2 + .25\ \Omega^2)$.

To use this equation in practice we first find α on the assumption that s is infinite. We then try a slightly different value and so solve the equation (4) by trial and error, using the value of Ω for normal R.P.S.

We may proceed on similar lines in other and more complicated cases.

COMPARISON OF AIRCRAFT

BY

R. J. MOFFETT, A.F.R.Ae.S., A.M.I.Ae.E.

Many " figures of merit " for the comparison of aircraft have been advanced at various times, but in those cases where the basis of comparison has been logical no consideration has been given to first cost, while in those cases where money cost is included, serious objections can be raised to the value of the comparison made.

The following comparative method is suggested as being logical despite the complete neglect of maintenance costs, which offer the most serious difficulty in obtaining unique comparisons of any mechanical systems. However, a consideration of estimated maintenance costs from experience of similar types, used in conjunction with the " economy figure " suggested, should form a sound basis from which to choose the type most suitable for any particular operation.

First consider the machine, whether truck or aircraft, from the physical operations point of view only, neglecting all capital costs.

Let E = operating efficiency.

U = useful load in lbs. or tons, *i.e.*, gross weight less weight empty.
R = range or distance of operation in miles.
P = average power developed in b.h.p. for economical operation.
T = time, in hours, required to travel distance R.
V = economical speed of operation in m.p.h.

The revenue producing capacity of any transport machine is expressed in units of " ton miles " only, as for all normal transport requirements the machine has nothing else to offer. This perhaps may be modified in the case of aircraft carrying luxury express or mail, to " ton miles per hour," but this is considered a special case as normal transport is interpreted as " most economical movement of goods."

The energy cost of producing these ton mile units is expressed in terms of brake horse-power hours, neglecting any peculiarities of loading the machine.

Then operating efficiency is expressed as the ratio of revenue producing capacity and energy cost, or

$$E = UR/PT$$

but R/T is the average speed of the machine, which should be the most economical speed of operation, so that

$$E = UV/P.$$

Before proceeding further, consider the dimensions of this expression :—

U, a load, has the dimensions (MLT^{-2}).
V, a speed, ,, ,, (LT^{-1}).
P, power, ,, ,, (ML^2T^{-3}).

So that, dimensionally, the expression has the value

$$\frac{(MLT^{-2})\,(LT^{-1})}{(ML^2T^{-3})} = 1$$

that is, E, the operating efficiency, is non-dimensional, a fundamental requirement for any efficiency figure.

It is of interest to note here, that if the revenue producing capacity is taken as " ton miles per hour," E has the dimension of T^{-1}, indicating that in this case, time is of first importance.

In the special case of aircraft, where the weight of the crew plus the weight of fuel for a given range may be a considerable proportion of the total useful load, it would seem necessary to find this efficiency figure for more than one range, on the assumption that some types may be more efficient for long range work. Assuming that curves are to be drawn of operating efficiency against range, consider the efficiency figure for zero range.

Let E_o=" no range " operating efficiency.
U_o=" no range " useful load, *i.e.* total useful load less weight of crew.

Then $E_o = U_o V/P$.

To obtain the operating efficiency for any given range, U_o must be decreased by the weight of fuel required.

Let E_R=operating efficiency for given range.
U_R=net useful load for given range.
$= U_o - W$,

where W=weight of fuel required

Then

$$E_R = U_R V/P = (U_o - W) V/P$$
$$= U_o V/P - WV/P$$
$$= E_o - WV/P.$$

Now W can be expressed in terms of brake horse-power and hours, *i.e.*,

$$W = wPT$$

where w=consumption of fuel per b.h.p. hour.

Also we know that

$$T = R/V$$

therefore

$$W = wPR/V$$

so that

$$E_R = E_o - (wPRV/V)/P$$
$$= E_o - wR.$$

That is, assuming the same types of fuel and power unit, the " no range " operating efficiency figure can be used for direct comparison, because for any given range the reduction in efficiency is directly proportional to the range.

Obviously, if two machines using different types of fuel are to be compared, range efficiencies must be calculated.

This permits further simplification. Cruising (in the sense of most economical) speeds and powers are usually not known accurately for aircraft, and it is suggested that " no range " efficiency figures should be calculated from maximum speed and rated horse-power. Undoubtedly this will horrify a host of critics, but the writer has applied this method to many types of aircraft, and in those cases where cruising speeds and powers were known with reasonable accuracy, while the arithmetical value of the figures changed, the relative order of merit remained the same. So long as all types are considered on the same basis, the relative error is not serious.

Having obtained this efficiency figure without reference to money price, it can be related to operating costs as follows:—

It is assumed first, that the cost of the crew will be the same, and that the cost of producing one brake horse-power hour will be the same, within reasonable limits, for any two comparable types of machine This assumption appears to

be reasonable and disposes of direct operating costs with the exception of maintenance.

For any particular operating conditions, indirect costs, *i.e.*, interest on capital investment, obsolescence, insurance, etc., are usually a percentage of the money price of the equipment used.

Then by dividing the money price of the machine by the machine " no range " efficiency figure we obtain the money cost per unit of efficiency, a figure including the effect of all direct and indirect operating costs except maintenance, and the criterion of economy becomes " the machine with the least first price per unit efficiency is the most economical," with the proviso that maintenance costs must also be compared, and the final decision reached in conjunction with the economy figure.

The final figures for comparison then become

$$E_o = \frac{(\text{net useful load at no range}) \times (\text{max. speed})}{\text{rated b.h.p.}}$$

and

$$\text{Economy figure} = \frac{\text{Price of machine}}{E_o}$$

SUMMARY OF THE SOCIETY'S ACTIVITIES
DECEMBER, 1933—DECEMBER, 1934

The following places on permanent record in the Journal the notices which have appeared in the Monthly Notices inset in the Journal, and so summarises the activities of the Society for the year. Activities not reported in this summary will be given in the Annual Report of the Council, published in the Journal for March, 1935.

Council and Officers, 1934-35

President:

Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.I.Ae.E., M.P.

Past-President:

Mr. C. R. Fairey, M.B.E., F.R.Ae.S.

Vice-Presidents:

Sir John D. Siddeley, C.B.E., F.R.Ae.S.
Mr. H. E. Wimperis, C.B.E., F.R.Ae.S.

Council:

Captain P. D. Acland.
Major J. S. Buchanan, O.B.E., A.M.I.Mech.E., F.R.Ae.S.
Mr. R. S. Capon, O.B.E., B.A., F.R.Ae.S.
Mr. E. C. Gordon England, F.R.Ae.S.
Mr. A. H. Hall, C.B.E., M.Inst.C.E., M.I.Mech.E., F.R.Ae.S.
Mr. S. Scott-Hall, A.C.G.I., M.Sc., D.I.C., A.F.R.Ae.S.
Mr. F. T. Hill, F.R.Ae.S., M.I.Ae.E.
Captain A. G. Lamplugh, F.R.G.S., F.R.Ae.S., M.I.Ae.E.
Mr. M. Langley, M.I.Ae.E., A.M.Inst.N.A.
Mr. W. O. Manning, F.R.Ae.S.
Major R. H. Mayo, O.B.E., M.A., Assoc.M.Inst.C.E., F.R.Ae.S.
Mr. D. R. Pye, M.A., F.R.Ae.S.
Mr. E. F. Relf, A.R.C.S., F.R.Ae.S.
Mr. W. P. Savage, A.F.R.Ae.S.
Lieut.-Col F. C. Shelmerdine, C.I.E., O.B.E., A.F.R.Ae.S.
Mr. F. Sigrist, M.B.E., F.R.Ae.S.
Mr. O. E. Simmonds, M.A., M.P., F.R.Ae.S., M.I.Ae.E.

Hon. Treasurer:

Major D. H. Kennedy, O.B.E., F.R.Ae.S.

Solicitor:

Mr. Lawrence A. Wingfield, M.C., D.F.C., A.R.Ae.S.I.

Hon. Librarian:

Mr. J. E. Hodgson, Hon. F.R.Ae.S.

Hon. Accountant:

Mr. A. N. D. Smith, F.C.A.

Secretary and Editor:

Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

Committees of Council

The following Committees of Council were appointed for 1934-35:—

Grading Committee:

Captain F. S. Barnwell, Mr. R. A. Bruce, Major G. P. Bulman, Major F. A. Bumpus, Mr. W. S. Farren, Lieut.-Col. L. F. R. Fell, Mr. A. Gouge, Capt. F. T. Hill, Mr. R. J. Mitchell, Mr. W. P. Savage, Lord Sempill and Prof. R. V. Southwell and Dr. H. C. Watts.

Finance Committee:

Captain P. D. Acland, Mr. Griffith Brewer, Mr. H. Burroughes, Mr. E. C. Gordon England, Mr. C. R. Fairey, Captain F. T. Hill, Mr. J. E. Hodgson, Major D. H. Kennedy, Captain A. G. Lamplugh, Mr. John Lord, Mr. F. R. Simms, Mr. A. N. D. Smith and Mr. L. A. Wingfield.

Lectures Committee:

Major T. M. Barlow, Major G. P. Bulman, Mr. R. S. Capon, Captain F. Entwistle, Mr. A. Gouge, Mr. S. Scott-Hall, Mr. M. Langley, Mr. W. O. Manning, Mr. D. R. Pye and Mr. E. F. Relf.

Joint Standing Committee with the Society of British Aircraft Constructors and the Royal Aero Club:

Prof. L. Bairstow, Lord Sempill and Lieut.-Col. F. C. Shelmerdine.

Education and Examinations Committee:

Major T. M. Barlow, Prof. L. Bairstow, Mr. R. S. Capon, Mr. W. E. Dumbrill, Captain F. T. Hill, Prof. B. Melvill Jones, Mr. M. Langley, Mr. W. M. Page, Dr. N. A. V. Piercy, Mr. R. K. Pierson, Mr. D. R. Pye, Mr. W. P. Savage, Mr. H. T. Tizard, Captain G. S. Wilkinson and Mr. L. A. Wingfield.

Medals and Awards Committee:

Major T. M. Barlow, Mr. Griffith Brewer, Sir R. Brooke-Popham, Major J. S. Buchanan, Mr. A. H. R. Fedden, Group Captain G. B. Hynes, Mr. W. O. Manning, Sir A. Verdon-Roe, Mr. G. R. Volkert, Mr. C. C. Walker, Mr. H. E. Wimperis, Mr. L. A. Wingfield and Mr. R. McKinnon Wood.

Amulree Committee:

Lord Amulree, Prof. L. Bairstow, Mr. Griffith Brewer, Mr. C. R. Fairey, Lord Gorell, Major D. H. Kennedy, Lord Mottistone, Lord Sempill and Mr. H. E. Wimperis.

Students' Flying Club Committee:

Captain P. D. Acland, Major D. H. Kennedy, Mr. M. Langley, Mr. O. E. Simmonds, the Secretary of the Students' Section and the Chairman of the Students' Section.

Rules Sub-Committee:

Professor L. Bairstow, Mr. Griffith Brewer, Mr. A. H. Hall, Major D. H. Kennedy, Mr. W. O. Manning, Lord Sempill and Mr. L. A. Wingfield.

REPRESENTATIVES ON OTHER BODIES.

Aerodromes Advisory Board: Mr. C. R. Fairey, Lord Sempill, Squadron Leader Nigel Norman and Mr. Ivor McClure.

British Standards Institution Aircraft Committee: Major R. H. Mayo and Dr. H. C. Watts.

Advisory Council of the Science Museum: Lord Sempill.

National Central Library: Mr. J. E. Hodgson (Hon. Librarian).

Students' Section: Mr. G. L. H. Bott (Honorary Secretary).

Association of Special Libraries and Information Bureau: Mr. J. E. Hodgson (Hon. Librarian).

***Advisory Committee on Aeronautical Education of the Imperial College*: Mr. C. R. Fairey.**

British Corporation Register of Shipping and Aircraft, Aviation Committee: Lieut.-Col. J. T. C. Moore-Brabazon and Lord Sempill.

Seagrave Memorial Fund Committee: Mr. C. R. Fairey.

British Gliding Association: Council: Mr. W. O. Manning.
Technical Committee: Capt. J. L. Pritchard, Capt. F. T. Hill.

Air League of the British Empire: Mr. W. O. Manning and Mr. Griffith Brewer.

British Science Guild: Mr. C. R. Fairey.

Professional Classes Aid Council: Lord Sempill.

Annual General Meeting

The Annual General Meeting of the Society was held on Tuesday, March 27th, 1934, in the Library at 7, Albemarle Street, W.1.

Present:—Mr. C. R. Fairey (*President*) in the chair.

Captain P. D. Acland.
Major J. S. Buchanan.
Major G. P. Bulman.
R. S. Capon.
C. N. Colson.
A. H. Hall.
S. Scott-Hall.
F. T. Hill.
Major D. H. Kennedy (*Hon. Treasurer*).
W. O. Manning.
Lt.-Col. J. T. C. Moore-Brabazon.
P. R. Nazir.
D. R. Pye.
G. Tilghman Richards.
R. Ross.
W. P. Savage.
Lord Sempill.
Lt.-Col. F. Shelmerdine.
O. E. Simmonds.
H. T. Tizard.
T. H. Turner.
H. E. Wimperis.
L. A. Wingfield (*Solicitor*).

Captain J. L. Pritchard (*Secretary*).

The Secretary read the notice convening the meeting.

The President reported on the work of the Society for the year and the financial position of the Society. He said:—

For the fourth year in succession I have the privilege, as President, to review the work of the Society for the past year. It has been a quiet but hopeful year, and one which does not call for much comment.

I will only consider the chief points in the report, but I should like to say that this is an occasion when members have every opportunity to raise any points they wish, and I hope that any present will not hesitate to do so.

Our Society goes from strength to strength and is growing steadily and surely in prestige, in the scope of its activities, and of usefulness to its members. The last three years have been the most difficult of post-war years, during which many of our leading institutions have lost members and have been compelled to

curtail their activities. The Society's position, however, is a reflection of the real strength of aviation. Where other institutions have lost members, we have shown an actual increase. It is small, but there is every sign that it is permanent, and we may hope for further real progress in the future.

Last year I drew attention to the depressing effect on aviation by reason of the fact that it was made the scapegoat of disarmament, and there was much misguided talk about such matters as international control. Now, fortunately, more reasonable views appear to be gaining ground, and there is great hope that the Gorell Committee and the Cabinet Committee now sitting will remove some of the restrictive influences that have curtailed civil development in this country and will open up new prospects.

There are on all hands signs of increased attention to the importance of aviation. Such questions as air mail, passenger transport and defence, are coming more and more into the limelight, and the importance of the scientific and technical aspects of these problems is at last being recognised.

It is manifest that the problems confronting the aeronautical engineer grow in number and complexity with every phase of development. The initial problem, however difficult of solution, was simple in essence—it was merely to fly. That stage has long passed, and it is now obvious that the future depends as much on scientific and technical development as on any form of external support.

A healthy sign of progress is the increased membership of the branches. In 1931 and 1932 there was a heavy falling off in membership. The prosperity and activity of the branches depend very largely upon the corresponding progress in the industry, as so many of the branches are based upon the proximity of aircraft works. Here I would like to pay a tribute to the work and enthusiasm of all those Branch Secretaries and Committees who have given their time and energy to keeping the branches going in the face of great difficulty. The Council are very anxious to encourage in every possible way the very useful work the branches are doing, and they hope that all members of the Society who can will do all they can to aid the work of their local branch.

This is the third year that the Society has arranged for lectures before the public schools and other educational centres. These lectures have not only proved of the greatest interest and value, but they have stimulated a growing demand for outside lectures which has had to be met by a big increase in the number and variety of the slides now in the Society's collection. That collection contains over 3,000 slides, and outside the Air Ministry collection—the majority of which are not available for public use—the Society's aeronautical slide collection is the largest in the world. I wish particularly to thank all those who have so willingly helped for the third year in succession to make the public schools lectures such a success. Lectures have been delivered before over 200 schools, and altogether in the past three years the Society has arranged for lectures to over 50,000 people. In the opinion of the Council these lectures are a form of propaganda which is invaluable for making the country air-minded.

While I am speaking of the slides, I should like to draw attention to the Society's collection of aeronautical photographs which was begun by the Secretary three years ago. I particularly wish, in the first place, to thank all those manufacturers and individuals who have come forward with photographs of all kinds and have also given so many slides to the Society. Not only have firms and individuals in this country helped, but the leading aeronautical firms throughout the world, and the air authorities, through their Air Attaches in this country, have most generously co-operated to make the collection one of the most representative of its kind. The total number of photographs is now well over three thousand—all mounted and indexed for easy reference.

It is a tribute to the work of the Finance Committee, under the able Chairmanship of the Honorary Treasurer, Major Kennedy, that much of this work has been able to be carried on. He has kept a constant and watchful eye on the

finances, and this year the excess of expenditure over income, excluding the donations, is only £19 compared with a similar loss last year of £115, of £159 in 1931, and £186 in 1930.

We are not yet out of the financial wood, and it is largely due to the generous donations from the Air Ministry, the Society of British Aircraft Constructors, and the Society of Motor Manufacturers and Traders that the Society has been able to carry out the work which it should do. Therefore, I would like to put on record our profound gratitude to these Institutions for their timely help. Both the Air Ministry and the S.B.A.C. contribute not only funds, but we have the active support on Council, Committees, and elsewhere of members from both bodies. I would like to assure them that both their money and their activities are very well used, and their support is duly appreciated. There are many projects which the Council have in view, and they wish to impress upon every member of the Society that the time is not yet when the Society can be considered self-supporting.

A financial aspect which has been engaging the earnest attention of the Council is the progress of the Endowment Fund. Started in 1926 with the object of building up a fund to enable the Society to have its own premises, it amounted at the end of that year to £575. At the end of 1930 the fund had risen to £1,950, and there followed those difficult three years which left the fund almost stationary.

During 1933, however, the Council made arrangements for the Endowment Fund to be made a Trust Fund, and have transferred to it the greater part of the investments in Aerial Science Limited. Under the terms of the Trust Fund the amount which is accruing may only be spent with the specific object of providing the Society with its own building and lecture theatre. The fund now amounts to £9,700. The Council is aiming at a fund of at least £50,000, and I hope that every member will do his utmost to help the Council to attain their object, as it will not only enable the Society to have its own premises but would enable it to be independent of the fluctuations of membership subscriptions and donations and enable it to go ahead with many schemes now held in abeyance. Such a sum would put the Society in a very powerful position which could not but react for the benefit of every member.

It is very largely due to the very excellent work of our Honorary Accountant, Mr. Norman Smith, that the Society is now free from income tax. This results in a very large saving annually. This is the seventh year that Mr. Smith has so ably helped the Society, and due to his wise advice on our investments we are gaining strength financially year by year. He has received able co-operation from Mr. Wingfield, the Society's Solicitor, who has been responsible for all the legal transactions of the Society and who has for some years willingly and freely advised the Council in all legal matters.

This is the eleventh year in succession that Mr. Hodgson has acted as Honorary Librarian to the Society, and it was with very great pleasure indeed that the Council were able to recommend, a month or so ago, to the members that Mr. Hodgson should be elected an Honorary Fellow of the Society. This is a long overdue honour, for in Mr. Hodgson we have the leading authority in the world on the history of aviation. The whole of his unrivalled knowledge has been most generously placed at the disposal of the Society, who owe him a real debt of gratitude. There are many others who have worked on behalf of the Society during the year, notably members of the various Council Committees, and the Council wish publicly to thank them for the time which they have given—often at considerable expense to themselves. Every Society must rely very largely upon this voluntary help, but I think that the Royal Aeronautical Society is particularly fortunate in its own members, who are so zealous in looking after its interests.

The Students' Section of the Society continues to grow in a most gratifying manner. It is one of the largest sections of the Society, and the Council have had under consideration various new ways in which it may be encouraged. There is, for example, under consideration at the present time a proposal to form for the students a Flying Club. There are many difficulties in the way, but it is hoped that the way may be found to provide students with flying facilities, which undoubtedly will be of very great help in their work.

Before closing this short review of the past year, I should like to say a few words about the staff. It is the smallest staff of any similar-sized body. Upon it depends the real success of the Society. It is easy for the Council to say: Do this and do that; but often a few minutes' discussion in the Council may lead to weeks of work by the staff—to make the suggestions of the Council successful. During the year the Council suffered the loss of the services of Miss Jarvis through very serious illness, and I should like to pay tribute to the work which she did so ably, not only on behalf of the Society but the Institution of Aeronautical Engineers. Her place has been taken by Miss Barwood, who served the Society for many years and who has now returned. I should like to pay special tribute to Miss Todd, who has been responsible for certain work in the Society that is of very real value. She is entirely responsible, for example, for the List of Members from beginning to end and for seeing it through the Press. It is a tribute to her work that the number of complaints of wrong entries does not amount to ten in a year. Miss Voyce is responsible for the books of the Society, and a very well-deserved tribute has been paid to her by the auditors, Messrs. Price, Waterhouse and Company, for the very excellent way in which the Society's accounts have been kept. These are only major points in their work, but I do wish, gentlemen, to impress upon you that the reliability of the staff is 95 per cent. of the Society's prosperity.

Last, but far from least, I would like to refer to the outstanding work of our Secretary, Captain Laurence Pritchard. Only those of us in intimate contact with him realise what a tower of strength he is to the Society and how much we owe to him. He is not only extremely energetic in every aspect of the Society's activities, but he shows by his unselfish devotion to all our work that he has the Society's interests thoroughly at heart. I do not know what we should do without him, and I wish to offer the sincerest expression of our gratitude.

May I remind you that the Annual General Meeting gives an opportunity for members to put forward their views as to our past activities and future efforts. I hope anyone present will not hesitate to do so. The policy of the Council is governed by the wishes of the members, and we welcome either advice or criticism and suggestions of any kind that can be of future benefit to the Society.

Mr. Wimperis raised the question of various items on the balance sheet as not showing a true statement of the Society's financial position. Grants could not be counted on indefinitely, although they might be needed. The Society had received £631 5s. in donations this year and had been in receipt of donations for several years past, and was showing a loss without these donations. It was necessary to draft some state of the Society's funds, as the present statement did not show that the Society still depended on donations. Casual donations could not be called regular income.

Mr. Wimperis also raised the question of recovery of income tax, and asked whether it was known that the period was limited to six years.

Major Kennedy (Honorary Treasurer) replied that the whole of the income tax had been recovered.

Mr. Tizard asked why the Income and Expenditure Account had not been audited, but the Honorary Treasurer pointed out that this had been done. He also asked why the various prizes had not been awarded and the funds allowed

to accumulate. The Secretary pointed out that no entries had been received as such, and that conditions varied with each prize.

Mr. Tizard considered that all lectures read before the Society should be taken as entries for the appropriate prizes. The President said he would have the matter discussed at the next meeting of Council.

Mr. Tizard enquired why the surplus cash of the Pilcher Prize and R.38 Prize had not been invested. The Secretary said this would be looked into.

Lord Sempill said one aspect of the expenses, as mentioned by Mr. Wimperis, had not been clearly shown in the accounts, but he believed this was due entirely to the generosity of the President, which the Honorary Treasurer could no doubt enlarge upon.

Major Kennedy (Honorary Treasurer) agreed that this was so.

Mr. Tizard mentioned the Gold Medal founded by Mr. Fairey and said he would like to know more about the conditions of the award. He thought it was very necessary to make these conditions more accessible to members.

The Secretary said this would be attended to.

The President then reported that ten nominations only had been received for the ten vacancies on the Council. The Secretary read the names of the candidates, with their proposers and supporters, as follows:—

Name.	*Proposer.*	*Seconders.*
R. S. Capon.	H. E. Wimperis.	D. R. Pye. H. L. Stevens.
E. C. Gordon England.	C. R. Fairey.	Lord Sempill. P. D. Acland.
*S. Scott-Hall.	Lord Sempill.	F. Handley Page. L. Bairstow.
*F. T. Hill.	L. Bairstow.	H. Roxbee Cox. W. S. Farren.
*W. O. Manning.	A. G. Lamplugh.	John Lord. J. D. North.
*J. T. C. Moore-Brabazon.	F. Handley Page.	T. H. England. Lord Sempill.
D. R. Pye.	H. E. Wimperis.	H. T. Tizard. R. V. Southwell.
E. F. Relf.	B. Melvill Jones.	W. S. Farren. A. Fage.
*W. P. Savage.	G. P. Bulman.	A. A. Ross. G. S. Wilkinson.
*H. E. Wimperis.	H. M. Cave-Browne-Cave.	D. R. Pye. G. P. Bulman.

* New Members of Council.

On the proposal of Captain Acland, seconded by Mr. Wimperis, Messrs. Price, Waterhouse and Company were elected as Auditors for Aerial Science Limited and Aeronautical Trusts Limited for the ensuing year. The proposal was carried unanimously.

The President left the room at this stage and Lord Sempill took the chair.

The Secretary then read the resolution on Item 4 of the Agenda:—

> "To consider a further suspension of Rule 71 as suspended at a Special General Meeting held on June 9th, 1932."

Mr. Tizard said he considered the resolution was not in order as he read the rules. The notice convening the meeting should have clearly stated the exact alteration proposed to Rule 71.

After some discussion the Chairman said, as far as he could see, the rules had been followed and the procedure was in order.

The Secretary read Rule 107 and suggested that this rule meant that rules could be altered at an Annual General Meeting.

Mr. Tizard then raised the point that due notice should be given. The rules were so drawn up that it was clearly stated what form the alteration to the rules should take.

Lord Sempill believed it was in order, and in accordance with precedence, and asked that it may be taken that it was in order as the rules now stood.

Captain Acland said the suggestion before the meeting was that powers be taken to extend the period for one year so that Mr. Fairey should continue his extremely good work for one year more. It was very difficult to say just how much the President had done and how much he has helped the Society with his work in connection with the Endowment Fund and work for the welfare of the Society. He thought it was in the interests of the Society that the President should continue in office for a further year to continue the work he had started. Captain Acland said he was speaking with the knowledge of the amount of work which falls on the President of the Society.

The resolution was proposed by Major Kennedy that Rule 71 be suspended and was seconded by Mr. Manning. The resolution was defeated.

Mr. Wimperis said it was not in the best interests of the Society to make alterations in the rules in the emotion of the moment, although he yielded to no one in his admiration of Mr. Fairey's work and generosity. None of the big engineering institutions elected their Presidents for more than one year. There was a tendency to depart from the old rules. He agreed that when the Society was going through a crisis it was in its interest to adopt such steps, but it could not be said that the Society was in such a bad state now. He did not approve of the entire suspension of Rule 71.

Colonel Moore-Brabazon pointed out that had the Society adhered to Rule 71 there would have been five Presidents over the bad period. He did not agree that the difficult period was over. He said times were exceptional, and the man was exceptional, so that he agreed to the change in the rule.

Mr. Tizard said he agreed with Mr. Wimperis. It was wise of the Council to extend the rule for two years, but not for four years. The strength of the Society was such that it ought not to deprive prominent members of the Society of the great honour of Presidency. Mr. Fairey's generosity was not dictated by the Presidency or otherwise. He understood a big exception was made at the time, but the proposed extension was not warranted.

After further discussion the proposed extension of Rule 71 was defeated on a show of hands by 12 votes to 7.

Mr. Tizard then put the following motion, which was seconded by Mr. Wimperis and carried:—

> "That this Annual General Meeting draws the attention of the Council to the absence in the rules of any regulations laying down precisely the procedure which should be adopted in the event of a change in the rules being proposed; and requests the Council to consider the matter, and to submit proposals to the next Annual General Meeting or to a Special General Meeting."

President

Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.I.Ae.E., M.P., was elected President of the Society for the year 1934-1935 at the Council Meeting held on May 8th, 1934, and took office at the opening meeting of the 1934-35 Session of the Society on October 18th, 1934.

Lieut.-Colonel J. T. C. Moore-Brabazon holds No. 1 Royal Aero Club pilot's certificate and was the first English pilot to fly. He won the *Daily Mail* £1,000 prize for flying a circular mile in 1909 and was the first winner of the Empire British Michelin Cup. He was in the R.F.C. during the war and a member of the original Civil Aviation Committee. He became Parliamentary Secretary to Rt. Hon. Winston Churchill, the Secretary of State for Air, 1923; Parliamentary Secretary, Ministry of Transport, 1923-24, 1924-27; Chairman of the Air Mail Committee, 1923; has been Chairman of the Royal Aero Club; President of the Institution of Aeronautical Engineers, before its amalgamation with the Society; he was appointed Assessor at the R.101 inquiry, 1930-31; and is at present a Member of Parliament and member of a number of aviation committees.

Vice-Presidents

The following were elected Vice-Presidents of the Society for the year 1934-1935, at the Council Meeting held on May 8th, 1934:—

Mr. H. E. Wimperis, C.B.E., F.R.Ae.S.
Sir John Siddeley, C.B.E., F.R.Ae.S.

Mr. C. R. Fairey, M.B.E., F.R.Ae.S.

The retiring President, Mr. C. R. Fairey, M.B.E., F.R.Ae.S., has served four years, being specially re-elected in 1932 following the suspension of the Rule that a President may not serve for more than two years.

Mr. Fairey has served during one of the most difficult periods in the Society's history, a period of considerable financial difficulty, and one in which the great majority of societies have had definite set-backs in their membership. It is due to the wise guidance of the President that the Society during those years has continued to progress and to add to its membership. He has put the Society foremost during the whole of his period of office, has worked continuously on its behalf, and it is largely due to his own personal efforts that many important decisions of Council have been brought to successful conclusions. It is undoubtedly due to his influence, indeed, that the Society is playing an increasingly important part in aviation affairs.

Not the least help which has been given, help which has only been personally known in full to the Secretary, is financial. But for that help the Society would not be in the position it is to-day.

New Year Honours

In the New Year Honours' List appear the following:—

To be G.C.B.: The Rt. Hon. W. D. Weir, LL.D., D.L., *Fellow of the Society.*

To be K.C.V.O.: Sir Richard T. Glazebrook, K.C.B., *Fellow of the Society.*

To be C.B.E.: J. S. Buchanan, Esq., O.B.E., *Fellow of the Society.*

King's Birthday Honours

Viscount.—Lord Wakefield of Hythe, C.B.E., an Honorary Fellow of the Society.

C.B.E.—Captain Geoffrey de Havilland, a Fellow of the Society.

Elections

At the Council Meeting held on Tuesday, December 12th, 1933, the Council passed a resolution recommending to the next Ordinary Meeting of members of the Society that Mr. Griffith Brewer, F.R.Ae.S., and Mr. Orville Wright, Honorary Companion, be elected Honorary Fellows of the Society. At the Ordinary Meeting of members held on Thursday, December 14th, 1933, both the recommendations of Council were unanimously approved by the members present.

At a meeting of members held on February 1st, 1934, Mr. J. E. Hodgson, Honorary Librarian, was unanimously elected an Honorary Fellow of the Society in recognition of his work in the history of aviation and his work for the Society.

The following recommendations of the Grading Committee were approved by the Council:—

On December 12th, 1933:—

Fellows.—Nevil Shute Norway, Alfred Hessell Tiltman.
Associate Fellows.—Eric Shaw, William Henry Lewis.
Associate Member.—Bernard Elliott Dunkley.
Associates.—George McCorquodale Littlejohn, Vishva Nath Puri.
Students.—Thomas Allitt, Basil Peter Brooker, Percival George Brown, William Meikle Cochran, Cyril Lancelot Fellowes Colmore, Percy Reginald Dowden, Albert Edward Draper, Archibald James Edmunds, Ivor William Jones, James Leonard Barnard Jones, Howard John Kerr, Leonard Walter Kidney, Ronald John Knights-Whittome, Cecil Thomas Locke, David Ramsay Milne, Alan Edward Richards, Allin Beddoe Stephens, Stanley Francis Titt, John Henry Van, Godfrey Bernard Vinycomb, John Denis Walsh.
Companions.—Harry Gordon Selfridge, Jun., Alexander Robert Wright.

On January 23rd, 1934:—

Associate Fellows.—William Roy Baird, Roderick Peter George Denman, Herbert Geoffrey Morcom, Sydney Clifford Robertson, Hugh Gordon Wenham.
Associate Members.—Ellis Hill, Frederick John Ott.
Associates.—John Diedrich Ahlers, Robert Charles Morgan, Mahani Narayan Sitaram.
Students.—Eric Thomas Charles Frost, Ajit Ranjan Ghosh, William Frank Hilton, John Olding Hinks, David Francis Alastair McBain, Djelal Mahmoud-Bey, Thomas Graeme Finlayson Mathers, Henry Gerald Rossiter, Alan Howard Stratford, Harold Wray Tennant.

On February 20th, 1934:—

Fellow.—Harold Hemming.
Associate Fellows.—Sydney Hansel, Cyril Arthur Osborn, George Cecil Rhodes, Benjamin Henry Rolles, Bernard William Shilson, Richard Walter Walker.
Associates.—Frederick Charles Cooper, Hugh Crosby.
Students.—Edward Ellis Alexander Wood, Henry Udall.
Companions.—John Godsman Brown, Mohamed Aly Fahmy, Miss Rosalind Norman.

On March 13th, 1934:—

Fellow.—Miss Letitia Chitty.
Associate Members.—William Roy Baird, Harry Ledger.
Associates.—Captain the Earl Amherst, Hendrik Alexander Seyffardt.
Students.—Norman Weston Henrig, Harold Kember.
Companions.—John Lawrence Edwardes, Ambrosius Daniel Khan, Humphrey Charles Willis.

On April 10th, 1934:—

Associate Fellows.—Henry Frederick Vulliamy Battle, Miss Frances Beatrice Bradfield, Frank Beeton Ford, Frank Gill, Teny Kumpera, Gwilym James Richards.

Associates.—Francis Thomas Bradley, Ronald Denton-Samuel, Charles Exton Gardner.

On May 8th, 1934:—

Associate Fellows.—Wilfrid Barnard, Walter Frederick Dowsett, Frank Whittle.

Associates.—John Burt Flynn, Reginald Thomas Wood.

Associate Members.—Henry John William Coward, Cyril Donovan Tong.

Students.—Herbert George Kimber, Jamshed Earchshaw Shroff, George Richard Williams.

Companions.—Walter Noel Ash, Francis Robert Benjamin King, Cyril William Lawson.

On June 12th, 1934:—

Member.—Marcus Langley (from Associate Member).

Associate Fellows.—Charles Chapleo, Arthur George Bradford Metcalf.

Associates.—Francis John Hopgood, William James Williams.

Students.—Edward John Gregson, Harold Murphy, Jan Daniel Jacobus de Necker.

On September 11th, 1934:—

Associate Fellows.—Reginald Morville Davy, Frank Charles Lynam, Frederick James Sanger, Arthur Veryan Stephens, Frank L. Wattendorf, Kurt Hermann Weil.

Associate Member.—Jesse Henry Herbert Luxton.

Associates.—Edward Jordan, Rana Denis Shamsher Jung, James Edwin Henty, James Victor Saunders.

Students.—Roy Henry Lewis Arnold, Ernest Henry Cochrane, Donald Fraser, John Hargrave Lerew, John Godfrey Mathieson, Mervyn Lascelles Morris, Dennis Robert O'Brien, Richard Doniville Poland, John Roger St. Claire, Joseph Saoula, James Hay Stevens, Eric Thomas Watkinson, Edward Walpole Whitaker.

On October 23rd, 1934:—

Fellows.—William Jolly Duncan, Frederick Tymms.

Member.—Victor Samuel Gaunt.

Associate Fellows.—Geoffrey Uffindell Hayns, Frank Robert Coupland Hounsfield.

Associate Members.—Jack Glover, Joseph Williams.

Associate.—John Fort.

Students.—Reginald Philip Andrews, Ronald Bryce Bridges, Leonard Edward Christmas, Mahendra Narayan Guha, Austin Higgins, Gordon Jefferson, Cyril Woodward Taylor, John Wimperis, Alan Hampden Yates.

Companion.—Nigel Tangye.

On November 13th, 1934:—

Associate Fellows.—Edward Leslie Thomas Barton, Frederick Metcalf Thomas.

Associates.—John Campbell Corlett, Subodh Chandra Moitra.

Students.—Richard Antony Barnwell, William Davidson, Edward Peter Milway, Louis Alexander Howard, Arthur Oliver Mattocks, Kenneth Wilks.

Associate Fellowship and Associate Membership Examinations

Examinations for Associate Fellowship and Associate Membership were held in the Offices of the Society on March 23rd and 24th and October 2nd and 3rd, 1934. The following have satisfied the examiners in their respective subjects at the March examinations. No Students passed in the October examinations:—

ASSOCIATE FELLOWSHIP.

Strength of Materials and Theory of Structures.—W. Baillie, D. F. Horne, J. G. H. Pardoe, P. R. Poole, R. M. A. Rice, D. R. Sherwin, J. W. Sutcliffe, A. S. M. Wedderburn.

Applied Mathematics.—W. Baillie, D. Bamford, N. B. Berrington, A. H. Denny, D. F. Horne, J. G. H. Pardoe, R. M. A. Rice, J. W. Sutcliffe, A. S. M. Wedderburn, C. P. L. Nicholson.

Theory of Internal Combustion Engines.—W. Baillie, A. E. C. Carter, A. H. Denny, D. F. Horne, W. L. M. Denny, J. G. H. Pardoe, R. M. A. Rice, D. R. Sherwin, J. W. Sutcliffe, A. S. M. Wedderburn, N. R. Rustomjee.

Pure Mathematics.—P. R. Poole, N. R. Rustomjee.

Aerodynamics.—P. R. Poole.

Air Transport.—N. R. Rustomjee.

ASSOCIATE MEMBERSHIP.

Strength of Materials and Theory of Structures.—A. J. Cope, C. England, M. M. Prosser, G. W. Topping, H. Walker.

Applied Mathematics.—A. J. Cope, C. England, G. W. Topping.

Pure Mathematics.—H. Walker.

Theory of Internal Combustion Engines.—A. J. Cope, G. W. Topping.

Design (Aircraft).—H. Walker.

National Certificates and/or Diplomas in Mechanical Engineering

The following letters were exchanged during the year:—

To the Secretary of the Institution of Mechanical Engineers and the Secretary of the Board of Education.

10th May, 1934.

DEAR SIR,

National Certificates and Diplomas in Mechanical Engineering.

The Council of the Royal Aeronautical Society have instructed me to write to you with reference to the endorsement by the President of the Society of National Certificates and/or Diplomas in Mechanical Engineering in respect of Aeronautical Subjects where such are included in approved courses.

The Council would be glad if an arrangement for such an endorsement could be made on the understanding that the Assessor who would be responsible for the criticism of the examination papers and scripts would be appointed after consultation with the Royal Aeronautical Society.

Yours faithfully,
(Signed) J. L. PRITCHARD,
Secretary.

To the Secretary of the Royal Aeronautical Society.

T.500/285 (1). Board of Education, Whitehall, London,
20th June, 1934.

SIR,

I am directed to refer to your letter of the 10th May, 1934, and to state that the Board of Education agree to the proposal for the endorsement of National Certificates and/or Diplomas in Mechanical Engineering by the Royal Aero-

nautical Society in respect of Aeronautical subjects where such are included in approved schemes.

I am, Sir,
Your obedient Servant,
(Signed) H. B. WALLIS.

To the Secretary of the Royal Aeronautical Society.

The Institution of Mechanical Engineers,
Storey's Gate, St. James's Park, London, S.W.1,
18*th June*, 1934.

DEAR SIR,

National Certificates and Diplomas in Mechanical Engineering.

I have pleasure in informing you that the Council of this Institution have agreed to the proposal in your letter of the 10th May, 1934, for the Endorsement by the President of your Society of National Certificates and Diplomas in Mechanical Engineering in respect of Aeronautical Subjects where such are included in approved Courses on the understanding that the Assessor for these subjects would be appointed after consultation with the Society.

Steps will be taken in due course to put this arrangement into effect and to make the necessary announcements.

I am, Dear Sir,
Yours very truly,
(Signed) MAGNUS MOWAT,
Secretary.

Lectures

The following Lectures were read before the Society in 1934:—

January 18th.—" Ethyl," by Mr. F. Rodwell Banks, O.B.E., F.R.Ae.S.
February 1st.—" Engine Cowlings," by Mr. J. D. North, F.R.Ae.S.
March 1st.—" Speed and the Economics of Air Transport," by Major F. M. Green, O.B.E., F.R.Ae.S.
March 6th.—" The Relation of the Molecular Structure of Fuels to their Behaviour in Diesel Engines," by Mr. G. D. Boerlage and Dr. W. J. D. van Dyck. (Joint meeting with the Inst. of Aut. Engs. and other bodies.)
March 15th.—" Some Developments in Aircraft Construction," by Mr. H. J. Pollard, A.F.R.Ae.S.
April 19th.—" The Houston-Mount Everest Flight," by Air Commodore P. F. M. Fellowes, D.S.O.
April 26th.—" Landing in Fog," by Dr. Rüd. Stüssel.
May 31st.—22nd Wilbur Wright Memorial Lecture, " Stalling," by Professor B. Melvill Jones, A.F.C., F.R.Ae.S.
October 18th.—" The Education of Aeronautical Engineers," by Professor A. J. Sutton Pippard, F.R.Ae.S.
October 25th.—" The Compressed Air Tunnel," by Mr. E. F. Relf, F.R.Ae.S.
November 8th.—" Speeds of Commercial Aircraft," by Monsieur Louis Breguet.
November 15th.—" Flying Boats," by Mr. I. I. Sikorsky.
November 20th.—Discussion in the Library at 7, Albemarle Street, W.1, on " The Training of Aeronautical Engineers," at 6.30 p.m.
November 22nd.—" Air Turbulence near the Ground," by Prof. Dr. Wilhelm Schmidt.
November 29th.—" Engine Research," by Captain A. G. Forsyth.

December 6th.—" Flaps and other Devices as Aids to Landing," by Mr. R. P. Alston.

December 13th.—" Ferrous Metallurgy in Relation to Aircraft," by Dr. W. H. Hatfield, A.F.R.Ae.S.

Branch Lectures

January 2nd.—Lecture before the Bristol Branch by Mr. G. O. Anderson, A.M.I.Ae.E., on " Testing of Aero Engines."

January 4th.—Lecture before the Yeovil Branch by Flight Lieut. Nicholetts, on " The R.A.F. Long Distance Flight, 1933."

January 9th.—Lecture before the Manchester Branch by a Member of the Staff of Armstrong-Siddeley Motors, Limited, on " Compression Ignition Engines."

January 11th.—Lecture before the Gloucester Branch by Mr. Handley Page, on " Slots, Interceptors, etc."

January 18th.—Lecture before the Yeovil Branch by Mr. G. H. Field, on " Aluminium and its Alloys."

January 23rd.—Lecture before the Bristol Branch by Captain F. Entwistle, B.Sc., on " Meteorology."

February 1st.—Lecture before the Yeovil Branch by Captain G. T. R. Hill, on " Principles of Flight."

February 13th.—Lecture before the Bristol Branch by Professor R. V. Southwell, on " New Methods of Testing by Impact."

February 21st.—Lecture before the Manchester Branch, on " Flying Travel," by a member of the Staff of Imperial Airways.

February 23rd.—Lecture before the Gloucester and Cheltenham Branch, on " Soaring Flight," by Mr. C. Latimer Needham.

February 27th.—Lecture before the Bristol Branch, on " Record-Breaking Engines," by Mr. R. N. Dorey.

March 1st.—Lecture before the Westland Aircraft Society (Yeovil Branch), by Mr. E. F. Relf, F.R.Ae.S.

March 8th.—Lecture before the Cheltenham Branch by Mr. W. Hackett, on " Tubes."

April 5th.—Lecture before the Cheltenham Branch by Mr. A. H. R. Fedden, on " Engine Development."

October 18th.—" Flying between Kisumu and Cape Town on the Atalanta," Lecture before the Coventry Branch by Captain Caspareuthus.

October 18th.—Film of " Wings over Everest," before the Yeovil Branch.

October 25th.—Lecture before the Yeovil Branch by Mr. J. E. Hodgson, Hon. F.R.Ae.S., Hon. Librarian, Royal Aeronautical Society, on " Some Pioneers of the Aeroplane."

November 1st.—Lecture before the Westland Aircraft Society (Yeovil Branch of the R.Ae.S.) by Mr. G. H. Dowty, A.F.R.Ae.S., M.I.Ae.E., on " Aircraft Undercarriages."

November 15th.—Lecture before the Westland Aircraft Society (Yeovil Branch of the R.Ae.S.) by Mr. W. G. Gibson, A.R.Ae.S., M.I.P.E., on " Aircraft Production Methods."

November 15th.—Lecture before the Coventry Branch by Mr. W. C. Devereux, A.F.R.Ae.S., on " The Influence of Manufacture of Wrought and Cast Aluminium Alloys on Design."

November 29th.—Lecture before the Westland Aircraft Society (Yeovil Branch of the R.Ae.S.) by Mr. B. B. Henderson, on " The Modern Trend of Civil Aircraft Design."

December 13th.—Lecture before the Westland Aircraft Society (Yeovil Branch of the R.Ae.S.) by Sir Ernest W. Petter, M.I.Mech.E., on " The Trend of Military Aircraft."

December 20th.—Lecture before the Coventry Branch by Mr. W. S. Farren, M.B.E., M.A., F.R.Ae.S., on "Recent Aeronautical Research at Cambridge University."

December 20th.—Lecture before the Westland Aircraft Society (Yeovil Branch of the R.Ae.S.) by Mr. Leak, on "Cheap Light Aeroplane Design and Construction."

Public Schools' Lectures

The Council arranged for the fourth year in succession to give lectures before the Public Schools and other educational establishments. The success of these lectures depends largely upon the very willing help which members of the Society have given by undertaking to deliver a lecture to one of the schools.

As most members know, these lectures are arranged to give the minimum amount of trouble to the lecturer. Each lecture has about 40-50 slides and the lecture itself is written round the slides.

The Council hope that members will continue to volunteer to give one of these lectures, and they wish particularly again to thank all those who have given so much of their time to help in this way. The following is a list of the lectures:—

1. The History of the Aeroplane.
2. The Aeroplane and its Uses.
3. Seaplanes and Flying Boats.
4. Training Royal Air Force Pilots.
5. How Aeroplanes are Built and Fly.

Lectures before Public Schools, etc.

January 16th.—Lecture before the Northampton Town and County School, by Captain J. L. Pritchard, Hon. F.R.Ae.S.

January 17th.—Lecture before the Woolwich Polytechnic Engineering Society, by Mr. R. A. Wilmshurst.

January 29th.—Lecture before Nottingham High School, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

February 1st.—Lecture before Frensham Heights School, by F./O. R. E. G. Brittain.

February 1st.—Lecture before Porlock Institute, by Mr. C. T. Holmes.

February 2nd.—Lecture before Finchley Branch of Toc H, by Mr. W. E. Gray.

February 5th.—Lecture before Royal Grammar School, Worcester, by Mr. F. Radcliffe.

February 6th.—Lecture before Rossall School, Fleetwood, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

February 8th.—Lecture before the Gloucester and Cheltenham Branch, by Mr. Devereux.

February 10th.—Lecture before Highgate School, by Mr. W. O. Manning, F.R.Ae.S.

February 12th.—Lecture before St. Olave's School, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

February 12th.—Lecture before the Royal Liberty School, by Mr. H. B. Walker.

February 15th.—Lecture before Blackheath High School, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

February 16th.—Lecture before Leeds Grammar School, by Mr. G. C. F. Ely.

February 16th.—Lecture before Balshaw's Grammar School, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

February 17th.—Lecture before St. Peter's School, York, by Mr. G. C. F. Ely.

February 24th.—Lecture before Hurstpierpoint College, Sussex, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

March 2nd.—Lecture before Eccles Secondary School, by Mr. T. Hampson.

March 6th.—Lecture before Epsom College, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

March 10th.—Lecture before Eastbourne College, by Mr. S. Scott-Hall, A.C.G.I., M.Sc., D.I.C., A.F.R.Ae.S.

May 24th.—Lecture before Bishop Road Higher Institute, Bristol, on "The Uses of the Aeroplane," by Mr. W. Brierley, Associate Fellow.

October 6th.—Lecture before Bedales School, by Mr. W. O. Manning, F.R.Ae.S.

October 20th.—Lecture before Aldenham School, by Lieut.-Commander the Hon. J. M. Southwell, A.F.R.Ae.S.

October 22nd.—Lecture at East Ham Public Library, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

November 1st.—Lecture before Royal Grammar School, Newcastle, by Mr. J. Bell, A.R.Ae.S.I.

November 3rd.—Lecture before Berkhamsted School, by Lieut.-Commander the Hon. J. M. Southwell.

November 5th.—Lecture before Friern Barnet Literary Society, by Mr. G. O. Waters.

November 7th.—Lecture before Bristol Grammar School, by Captain F. S. Barnwell, F.R.Ae.S.

November 8th.—Lecture before Balshaw's Grammar School, by Mr. G. R. Irvine, A.M.I.Ae.E.

November 9th.—Lecture before Kingswood Grammar School, by Captain F. S. Barnwell, F.R.Ae.S.

November 9th.—Lecture before Queen Elizabeth Grammar School, Wakefield, by Mr. G. C. F. Ely.

November 9th.—Lecture before University College School, by Mr. W. O. Manning, F.R.Ae.S.

November 10th.—Lecture before Brighton College, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

November 10th.—Lecture before Dean Close School, Cheltenham, by Mr. K. J. Key.

November 15th.—Lecture before Ryde School, by Mr. T. H. Lloyd.

November 16th.—Lecture before Wyggeston School, by Mr. C. W. Lewitt, A.M.I.Ae.E.

November 17th.—Lecture before Trent College, by Mr. G. R. Irvine, A.M.I.Ae.E.

November 17th.—Lecture before Victoria College, Jersey, by Flt.-Lt. C. E. Maslin.

November 19th.—Lecture before Newcastle-under-Lyme School, by Mr. E. Hill, A.M.I.Ae.E.

November 22nd.—Lecture before The College, Cheltenham, by Mr. C. C. Copperthwaite.

November 23rd.—Lecture before Wolverhampton Education Dept., by Captain J. L. Pritchard, Hon. F.R.Ae.S.

November 26th.—Lecture before Medway Technical College, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

November 27th.—Lecture before St. Paul's School, by Mr. W. O. Manning, F.R.Ae.S.

November 28th.—Lecture before St. Germain's School, by Captain F. B. Fanstone, A.F.R.Ae.S.

December 3rd.—Lecture before the Institute of the Motor Trade, Manchester, on " The Coming of the Aeroplane," by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

December 10th.—Lecture before Bec School, by Mr. W. O. Manning, F.R.Ae.S., on " How an Aeroplane is Made and Flies."

December 11th.—Lecture before East Ham Public Library, by Mr. G. R. Irvine, A.M.I.Ae.E., on " The Uses of the Aeroplane."

December 12th.—Lecture before Berkhamsted School, by Commander the Hon. J. M. Southwell, A.F.R.Ae.S., on " How an Aeroplane is Made and Flies."

December 14th.—Lecture before Buxton Public Library, on " The Uses of the Aeroplane," by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

Students' Section

The following is a report of the activities of the Students' Section for the Session 1933-1934:—

The officers and members of committee elected at the Annual General Meeting on Wednesday, October 18th, 1933, were:—Chairman—Mr. R. J. Schmidt; Vice-Chairman—Mr. E. C. A. Backhaus; Secretary—Mr. G. L. H. Bott; Committee—J. P. Bertinat, F. G. R. Cook, J. Hanson, R. W. Hase, R. L. Lickley, W. J. S. King-Smith, C. W. Prower, G. H. Mansell.

The Inaugural Address was given by Mr. C. V. Dolby, on Tuesday, 24th October, 1933. The chair was taken by Lieut.-Colonel F. C. Shelmerdine.

The following meetings were held during the Session:—

Tuesday, Nov. 21st, 1933.—" The Use of Compressed Gas in Modern Commercial Aviation," by Mr. L. S. Campbell, Student. In the chair, Mr. F. T. Hill, F.R.Ae.S.

Tuesday, Dec. 5th, 1933.—Debate, " That Airships are not a Commercial Success." Proposed, Mr. C. D. Graham; seconded, Mr. J. W. T. Brackett. Opposed, Mr. J. A. Bailey; seconded, Mr. N. D. New. In the chair, Hon. A. de Moleyns.

Tuesday, Jan. 16th, 1934.—" Aerodromes in England," by Mr. G. H. Mansell. In the chair, Squadron Leader H. N. St. V. Norman, A.F.R.Ae.S.

Tuesday, Jan. 30th, 1934.—" The Covering of Aircraft Wings and Hulls," by Mr. E. C. A. Backhaus, Student. In the chair, Mr. F. A. Foord, A.F.R.Ae.S.

Tuesday, Feb. 13th, 1934.—" Some Notes on Stability of Aeroplanes," by Mr. R. J. Schmidt. In the chair, Dr. H. F. Winny, A.F.R.Ae.S.

Tuesday, Feb. 20th, 1934.—Informal discussion, " The Tendency in the Design of Modern Civil Aircraft," opened by Mr. M. Langley, M.I.Ae.E., and Mr. C. W. Prower.

Tuesday, May 15th, 1934.—" Aircraft Radio (Introductory)," by Mr. Hay Surgeoner. In the chair, Mr. R. P. G. Denman, A.F.R.Ae.S.

The average attendance at these meetings was eighteen.

Visits have been paid to the works of the following firms:—

The De Havilland Aircraft Co., Ltd.

Messrs. Handley Page, Ltd.

The Comper Aircraft Co., Ltd., jointly with Airwork, Ltd., Heston Airport.

Also to:—

The National Physical Laboratory.

The Royal Aircraft Establishment.

During this Session the Committee decided to arrange an informal supper for the Students' Section. This was held on November 28th, 1933, and proved a very successful innovation. Sixty-two members were present.

The Committee has also proposed that a Students' Flying Club be formed. The Council have given the matter their attention, and a special sub-committee has been formed to deal with it.

Awards

The following awards were made during the year:—

British Gold Medal for Aeronautics.—Captain Geoffrey de Havilland, C.B.E., A.F.C., F.R.Ae.S.

British Silver Medal for Aeronautics.—Messrs. C. W. A. Scott and T. Campbell Black.

Simms Gold Medal.—Sir Gilbert Walker, Kt., C.S.I., F.R.A.S., Sc.D., F.R.S., Ph.D., M.A.

Taylor Gold Medal.—Mr. A. Plesman.

Wakefield Gold Medal.—Senor Juan de la Cierva, F.R.Ae.S.

R.38 Memorial Prize.—An award of £10 10s. was made to Miss L. Chitty, F.R.Ae.S., for her paper entitled "Tapered Frameworks Representative of the Airship Hull."

Busk Memorial Prize.—Mr. A. V. Stephens, B.A.

Pilcher Memorial Prize.—Mr. W. H. Lewis, B.Sc., A.C.G.I., A.F.R.Ae.S.

Elliott Memorial Prize.—The two Elliott Memorial Prizes awarded each year have been awarded to Leading Aircraft Apprentice V. C. Darling and Leading Aircraft Apprentice W. Potts, of Halton.

Acknowledgments

The Council gratefully acknowledge the following:—From Mr. R. F. R. Pierce, "Charles Parsons," by Rollo Appleyard; from Ambert Villiers Air Motors, "Twenty-Five Years of Flying," by Harry Harper, "The Chemical Analysis of Iron," by A. A. Blair; from Mr. Barrington and Mr. Clarkson of the de Havilland Aircraft Company, lantern slides of various D.H. machines and engines; from Captain Norman Macmillan, several copies of the Proceedings of the Institution of Aeronautical Engineers, Notices to Airmen, etc.; the gift of a number of books for the Library from Mr. R. F. R. Pierce; and 14 photographs from the Department of Commerce, Aeronautics Branch, Washington, of U.S.A. aircraft; a film of the Wren light aeroplane from the designer, Mr. W. O. Manning; a series of 140 photographs of typical German aeroplanes, collected together by the German Air Ministry and forwarded through Dr. A. H. von Scherpenberg, the German Air Attaché, following a request from the Secretary; photographs of Potez aeroplanes, from Aeroplanes Henry Potez; photographs of aircraft manufactured by the Société Provençale de Constructions Aéronautiques; photographs of aircraft manufactured by Fiesler-Flugzenbau; photographs of aircraft manufactured by Avions Hanriot; photographs of "Avia 51" manufactured by Avia Constructions Aéronautiques Société Anonyme; photographs of machines manufactured by Avions Henri et Maurice Farman; photographs of aircraft manufactured by Société Anonyme des Ateliers D'Aviation Louis Breguet; photographs of aircraft manufactured by Société Anonyme Nieuport-Astra; photographs of aircraft manufactured by Chantiers Aéro-Maritimes de la Seine; photographs of aircraft manufactured by Les Ateliers de Construction du Nord de la France et des Mureaux; photographs of "Avions Dewoitine" manufactured by Société Aéronautique Française; photographs of aircraft manufactured by Koolhoven-Vliegtuigen; photographs of aircraft manufactured by Blériot-Aéronautique; films of American machines, presented by Messrs. Fred Kramer; a comprehensive set of lantern slides presented by Messrs. D. Napier and Son, Limited; from Mr. F. M. Walsh, complete set of the Journal for 1933; from Mr. Howard Flanders, the Journal for June, 1933, and February, 1934, R.100 Pamphlet, Catalogue of the Rheims Meeting, August, 1909, and Mr. Trois Grandes Courses par André

Beaumont, Journal of the Institution of Aeronautical Engineers, Vol. I, No. 3; from Dr. A. F. Zahm, Bibliography on Skin Friction and Boundary Flow, and eight pamphlets by himself on various topics in aerodynamics; from M. Jean Pontremoli, La Détonation et quelques Problèmes qu'elle pose, vus par le Constructeur de Moteurs; from Dr. Ing. Luigi Stipa, photographs of the Stipa-Caproni experimental aeroplane; from De Havilland Aircraft Co., Ltd., three photographs of the D.H. 86; from Société Industrielle d'Aviation Latécoère, photographs of their aircraft; from Louis du Rivau, photographs of aeroplanes; from Colonel E. Mossberg, Swedish Air Attaché, photographs of Swedish Aircraft; from Aero Tovarna Letadel Praha-Vysocany, photographs of aeroplanes; from Podlaska Wytwornia Samolotow, photographs of aeroplanes; from Mr. W. O. Manning, Fellow, a copy of "Animal Flight," by Dr. Hankin, and "Technical Electricity," by Davidge and Hutchinson; also copies of the Journal from Mrs. John Fullerton, Mr. R. F. R. Pierce and Mr. Thurstan James. They also wish to acknowledge the presentation of photographs from the following firms:—General Aviation Manufacturing Corporation, U.S.A.; Kellett Autogiro Corporation, U.S.A.; The Beech Aircraft Company, U.S.A.; Boeing Airplane Company, U.S.A.; Northrop Corporation, U.S.A.; The Waco Aircraft Company, U.S.A.; The Pennsylvania Aircraft Syndicate, Limited, U.S.A.; Aktiebolaget Svenska Jarnvagsverkstaderna, Sweden; Junkers-Werke, Germany; the presentation of photographs from the Glenn L. Martin Company, the Sikorsky Aviation Corporation and Amphibions Incorporated; the return of Journals for a number of years from Mr. P. T. Griffith, Associate Fellow; from Captain Keith Davies, Associate Fellow, rare historical notices of the first flight in India; and from Mr. J. E. Raddings three slides of the Radlock glider; a set of back numbers of the Journal from Mr. R. McKinnon Wood, Fellow; the loan of blocks from *Aircraft Engineering* to illustrate the paper by Mr. North and that on Cowling and Cooling of Radial Air-Cooled Engines; the receipt of 12s. 6d. towards the funds of the Society from Mr. L. S. Ash; photographs from the Bellanca Company, and a number of programmes of early flying meetings, catalogues and books, of historic interest, from Mr. C. G. Grey; a remarkable collection on permanent loan of modern technical German books, papers, pamphlets, etc., from Mr. E. C. Bowyer, Head of the Information Department of the Society of British Aircraft Constructors. This collection is one of the finest which has been gathered together and will form a most useful and necessary addition to the library of the Society; a collection of aeronautical pamphlets from Mr. H. R. Trost for the Society's collection; back numbers of the Journal from Air Commodore H. M. Cave-Browne-Cave; photographs from the Chance Vought Corporation; lantern slides from Lt.-Commander the Hon. J. M. Southwell; and a collection of N.A.C.A. Reports and Technical Notes from the Air Ministry; copies of back Journals of the Society from Mr. J. Hooley, Mr. C. Matson Hall and Mr. J. Zeidenfeld; a photograph of the Airspeed Courier from Airspeed, Limited.

International Index

An International Index to Aeronautical Technical Reports was prepared by the Society of British Aircraft Constructors, Ltd., and published by the Society at 5s. net. The index is one of British, American and Foreign Technical Reports.

Handbook of Aeronautics

The new edition of the Handbook of Aeronautics was published during the year in two volumes. It has been greatly enlarged and re-set and brought up-to-date. The first volume contains sections on Aerodynamics, Performance, Construction, Materials, Meteorology, Instruments, Wireless, Air Survey and Photography, Design Data and Formulæ, Design and Construction of Gliders and Sailplanes and general tables. The second volume is concerned entirely with aero engines

and airscrews. It is in itself an up-to-date treatise on aero engine design and practice as the following chapter headings show:—Design data; performance data; design and stress calculations; supercharging; carburettors and intake systems; cooling; ignition; fuels and fuel systems; lubricating oils and oil systems; exhaust systems and silencing; engine heaters and starting; testing of engines; compression ignition engines; and airscrews.

Obituary

The Council greatly regret to record the deaths of the following members of the Society:—

HERMANN GLAUERT, F.R.S., *Fellow.*

Mr. Glauert was struck and fatally injured by a flying fragment of wood while watching engineers blowing up the stump of a tree on Fleet Common, Hampshire, on August 4th, 1934.

Hermann Glauert was born in Sheffield on October 4th, 1892, and was the son of Mr. Louis Glauert. He was educated at King Edward VII School, Sheffield, and Trinity College, Cambridge, where he took a first class in the Mathematical Tripos, Part I, in 1911, and Part II in 1913. In the latter year he was awarded the Tyson medal for astronomy and related subjects. In the following year he was awarded the Isaac Newton Studentship in astronomy and physical optics and the Rayleigh prize for mathematics in 1915. He joined the staff of the Royal Aircraft Establishment in 1916, where he was engaged on aerodynamical research until his death, and in 1920 was elected a Fellow of Trinity and recently a Fellow of the Royal Society. He was elected a Fellow of the Royal Aeronautical Society in 1926.

Hermann Glauert made many important contributions to the science of aerodynamics. He was the author of numerous Reports and Memoranda of the Aeronautical Research Committee dealing with aerofoil and airscrew theory, performance, stability and control of aeroplanes, and the theory of the autogiro. His work, " The Elements of Aerofoil and Airscrew Theory," published in 1926, is a standard work on the subject. He contributed numerous papers in the Proceedings of the Royal Society and lectured before the Royal Aeronautical Society.

In 1922 he married Muriel Barker, B.Sc., and leaves two sons and a daughter, to whom the President and Council extend their deepest sympathy in her tragically swift bereavement.

The following appreciation of Mr. Glauert and his work from Mr. H. E. Wimperis, Director of Scientific Research, appeared in *The Times*:—

" The sudden death of Mr. Glauert is a serious loss to aeronautical science. As a Fellow of the Royal Society and a fellow of Trinity College, Cambridge, he was one of the chief of the research workers of the Air Ministry. His mathematical work in the field of aeronautics had won for him an international reputation, and he was this year appointed as head of the Aerodynamics Department of the Royal Aircraft Establishment at Farnborough. He was prominent, not only as the leader of a team of scientific workers, but as having made personal contributions of the highest value. Such men are rare and almost irreplaceable. His sudden death is a serious blow to his scientific friends and collaborators."

FLIGHT LIEUT. R. E. H. ALLEN, *Associate Member.*

Flight Lieut. R. E. H. Allen was accidentally killed by being run over. An Associate Member from 1923, he was an authority on ground transport in the Royal Air Force, on which he read a paper before the Society. He joined the staff at Scotland Yard and helped the police experiments for motor control from the air. He was indefatigable in his work on behalf of the Society in many ways, particularly in delivering many school lectures. His death was a very great blow to a large circle of friends.

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Technical Report of the Aeronautical Research Committee for **1924-25**. Vol. II.—Airscrews, Engines, Materials, etc.

R. & M.

No. **1304**, Torsional Resonance Characteristics of a Twelve-Cylinder Vee Aero Engine, B. C. Carter and N. S. Muir.
No. **1454**, Interferometer for Recording Turbulent Flow, L. F. G. Simmons and C. Salter.
No. **1521**, An Application of Prandtl Theory to an Airscrew, C. N. H. Lock.
No. **1522**, Interference between Bodies and Airscrews, Part II., C. N. H. Lock and H. Bateman.
No. **1537**, Methods of Representing Spar Tests, H. R. Fisher.
No. **1539**, Abstract, Flow Past Circular Cylinders at Low Speeds, A. Thom.
No. **1540**, Abstract, Convection of Heat from Isolated Plates and Cylinders in an Inviscid Stream, N. A. V. Piercy and H. F. Winny.
No. **1551**, The Radially Braced Airship Ring, L. Bairstow.
No. **1552**, Methods of Visualising Air Flow, K. W. Clark.
No. **1553**, Summary of the Present State of Knowledge Regarding Sheet Metal Construction, H. L. Cox.
No. **1554**, Buckling of Thin Plates in Compression, H. L. Cox.
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No. **1557**, Effects of Friction in Airscrew Drives in Damping Torsional Vibration, B. C. Carter.
No. **1558**, Tests of a Roots Type of Aircraft Engine Supercharger, Engine Experimental Staff, R.A.E.
No. **1559**, Use of Networks to Introduce Turbulence into a Wind Tunnel, E. Ower and R. Warden.
No. **1560**, Heat Transmission through Circular, Square and Rectangular Pipes, A. Bailey and W. F. Cope.
No. **1561**, Flow Near a Wing which Starts from Rest and then Stalls, Aeronautics Laboratory, Cambridge.
No. **1562**, Torsiograph Investigations With and Without a Spring Hub, with some Reference to Damping, B. C. Carter, N. S. Muir and H. Constant.
No. **1563**, Abstract, A Survey of the Air Currents in the Bay of Gibraltar in **1929-1930**, J. H. Field and R. Warden.
No. **1564**, Further Experiments on a Model Fairey III.F Seaplane, A. S. Batson and A. G. Gadd.
No. **1565**, Elastic Instability of a Thin Curved Panel, S. C. Redshaw.
No. **1566**, Wind Tunnel Interference on Wings, Bodies and Airscrews, H. Glauert.

No. 1567, Flexural and Shear Deflections of Metal Spars (Part I.), I. J. Gerard and H. Boden.

No. 1568, Calculation of Critical Reversal Speeds of Wings, D. M. Hirst.

No. 1569, The N.P.L. Open Jet Wind Tunnel, A. R. Collar.

No. 1570, Comparative Engine Tests with Petrol and Butane, P. H. Stokes and F. G. Code Holland.

No. 1571, Distortion of a Stripped Two-Spar Metal Wing under Torsional Loading, D. Williams and H. F. Vessey.

No. 1572, An Improved Multitube Tilting Manometer, R. Warden.

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No. 1577, Westland-Hill Pterodactyl Mark IV., A. S. Batson and J. E. Serby.

No. 1578, Model Spinning Tests of an Interceptor Fighter, A. V. Stephens and R. H. Francis.

No. 1579, Continuous Rotation Balance for Measurement of Yawing and Rolling Moments in a Spin, P. H. Allwork.

No. 1580, Frictional Drag of Flat Plates Below the Critical Reynolds Number, A. Fage.

No. 1581, Stresses in the Fuselage Induced by Gusts, H. R. Fisher.

No. 1582, Aileron Angles in High-Speed Manœuvres with Single-seater Fighters, B. V. Williams and J. H. Hartley.

No. 1583, Wind Tunnel Tests on Junker Type Ailerons, F. B. Bradfield and W. E. Wood.

No. 1584, Effect of a Contraction on the Turbulence in a Fluid Stream, A. Fage.

No. 1586, Stressing of a Fuselage under Combined Bending and Torsion, A. G. Pugsley.

No. 1587, Wind Tunnel Tests on:—
1. Frise Aileron with Raised Nose.
2. Hartshorn Aileron with Twisted Nose.
A. S. Hartshorn and F. B. Bradfield.

No. 1588, An Experimental Study of the Stalling of Wings, Aeronautical Laboratory, Cambridge.

No. 1589, A Modified Chattock Gauge of High Sensibility, V. M. Falkner.

No. 1590, An Experimental Investigation of the Wake Behind an Elliptic Cylinder, G. J. Richards.

No. 1591, Full-Scale Water Resistance of a III.F Seaplane in Steady and Accelerated Motion, E. T. Jones.

No. 1592, Heavy Flexible Cable for Towing A Heavy Body Below an Aeroplane, H. Glauert.

No. 1593, Effect of Wind on the Take-off of Seaplanes, E. T. Jones.

No. 1594, Landing and Take-off Speeds of Aeroplanes, R. S. Capon.

No. 1595, Aileron Stability, with Special Reference to Rolling Aileron Motion and the Influence of Frise Type Hinge Moment Curves, A. G. Pugsley.

No. 1596, Flexural-Torsional Flutter of a Simple Cantilever Wing, D. Williams.

No. 1597, Pressure Exploration over an Aerofoil that Completely Spans a Wind Tunnel, W. L. Cowley and G. A. McMillan.

No. 1601, Accuracy of Performance Measurement, J. L. Hutchinson and E. Finn.

No. 1605, Abstract, Flow Due to a Rotating Disc, W. G. Cochran.

No. 1606, Abstract, Stresses Induced by Flexure in a Deep Rectangular Beam, D. B. Smith and R. V. Southwell.

No. 1607, Abstract, A Modification of Oseen's Approximate Equation for the Motion in Two Dimensions of a Viscous Incompressible Fluid, R. V. Southwell and H. B. Squire.

No. 1610, Abstract, Analysis of Experimental Observations in Problems of Elastic Stability, R. V. Southwell.

AIR PUBLICATIONS

No. 129, R.A.F. Flying Training Manual, Air Ministry.

No. 1275, General Instrument Equipment for Aircraft, with Amendments, Air Ministry.

No. 1439, The Vildebeest Aeroplane, Pegasus I.M.3 Engine.

No. 1456, Manual of Air Navigation.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS (U.S.A.)

Technical Reports.

No. 466, Aircraft Power-Plant Instruments, Harcourt Sontag and W. G. Brombacher.

No. 467, The Experimental Determination of the Moments of Inertia of Airplanes, Hartley A. Soule and Marvel P. Miller.

No. 463, The N.A.C.A. High-Speed Wind Tunnel and Tests of Six Propeller Sections, J. Stack.

No. 464, Negative Thrust and Torque Characteristics of an Adjustable-Pitch Metal Propeller, E. P. Hartman.

No. 473, Strength of Thin-Walled Duralumin Cylinders in Compression, Eugene E. Lundquist.

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No. 475, Wing Pressure Distribution and Rotor Blade Motion of an Autogiro as Determined in Flight, John B. Wheatley.

No. 476, Relation of Hydrogen and Methane to Carbon Monoxide in Exhaust Gases from Internal-Combustion Engines, Harold C. Gerrish and Arthur M. Tessmann.

No. 477, Effect of Viscosity on Fuel Leakage between Lapped Plungers and Sleeves and on the Discharge from a Pump-Injection System, A. M. Rothrock and E. T. Marsh.

No. 478, Experimental Verification of the Theory of Wind-Tunnel Boundary Interference.

No. 479, Stability of Thin-Walled Tubes under Torsion, L. H. Donnell.

No. 480, The Aerodynamic Effects of Wing Cut-outs, Albert Sherman.

No. 484, A Flight Investigation of the Effect of Mass Distribution and Control Setting on the Spinning of the X.N.2.Y-1 Aeroplane, N. F. Scudde.

No. 486, Infra-red Radiation from Explosions in a Spark-Ignition Engine, Charles F. Marvin and Frank R. Caldwell.

Technical Notes.

No. 446, Appendix, Calculation of Horsepower Available. Appendix to Estimation of the Variation of Thrust Horsepower with Air Speed, Shatswell Ober.

No. 473, Tank Tests of Two Floats for High-Speed Seaplanes, J. W. Bell.

No. 474, Effect of Stabiliser Location upon Pitching and Yawing Moments in Spins as Shown by Tests with the Spinning Balance, M. J. Bamber and C. H. Zimmerman.

No. 476, The Effect on Engine Performance of Change in Jacket-Water Outlet Temperature, E. A. Garlock and Greer Ellis.

No. 479, Strength Tests of Thin-Walled Duralumin Cylinders in Pure Bending, Eugene E. Lundquist.

No. 480, The Drag of Streamline Wires, Eastman N. Jacobs.

No. 481, The Reduction in Drag of a Forward-Sloping Windshield, Eastman N. Jacobs.

No. 482, The Effect of Spray Strips on a Model of the Ps-M-1 Flying Boat Hull, John R. Dawson.

No. 483, Charts for Determining the Pitching Moment of Tapered Wings with Sweepback and Twist, Raymond F. Anderson.

No. 483, A Comparison of Several Methods of Measuring Ignition Lag in a Compression-Ignition Engine, J. A. Spanogle.

No. 484, A Method of Calculating the Performance of Controllable Propellers with Sample Computations, Edwin P. Hartman.

No. 486, The Effect of Trim Angle on the Take-off Performance of a Flying Boat, James M. Shoemaker and J. R. Dawson.

No. 487, Tests of Three Tapered Airfoils Based on the N.A.C.A. 2200, the N.A.C.A. M-6, and the Clark Y Sections, Raymond F. Anderson.

No. 488, A Complete Tank Test of a Flying Boat Hull with a Pointed Step—N.A.C.A. Model No. 22, James M. Shoemaker.

No. 489, Aerodynamic Characteristics of Anemometer Cups, M. J. Brevoort and U. T. Joyner.

No. 490, Tank Tests of Auxiliary Vanes as a Substitute for Planing Area, J. B. Parkinson.

No. 491, Tank Tests of a Family of Flying Boat Hulls, J. M. Shoemaker and J. B. Parkinson.

No. 492, The Aerodynamic Analysis of the Gyroplane Rotating Wing System, John B. Wheatley.

No. 493, Aerodynamic Rolling and Yawing Moments Produced by Floating Wing-Tip Ailerons, as measured by the Spinning Balance, Millard J. Bamber.

No. 494, Hazards to Aircraft Due to Electrical Phenomena, N.A.C.A.

No. 495, Effect of the Surface Condition of a Wing on the Aerodynamic Characteristics of an Airplane, S. J. de France.

No. 496, A Preliminary Motion-Picture Study of Combustion in a Compression-Ignition Engine, E. C. Buckley and C. D. Waldron.

No. 497, Full-Scale Drag Tests of Landing Lamps, C. H. Dearborn.

No. 498, Wind-Tunnel Measurements of Air Loads on Split Flaps, Carl J. Wenzinger.

No. 501, Landing-Shock Recorder, M. J. Brevoort.

No. 502, Aerodynamic Investigation of a Cup Anemometer, John D. Hubbard and George P. Brescoll.

No. 503, Measurement of Altitude in Blind Flying, W. G. Brombacher.

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Vol. XIII., No. 1 (Nos. 479-481) (In Japanese and English).
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Bulletin of the Institute of Physical and Chemical Research:—

Vol. XII., No. 10.
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Science Reports of the National Tsing Hua University. Series A, Mathematical and Physical Sciences:—

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Vol. I., Nos. 26-27.
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Journal of the Institution of Electrical Engineers, Vol. 72, January-June, 1933; Vol. 73, July-December, 1933. Edited by P. F. Rowell.

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Vol. LIII., No. 3, 1933.
Vol. LIV., No. 1, 1934.

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Proceedings, Vol. 124 (January-June, 1933).
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METEOROLOGY

China Rainfall and World Weather (Memoir of the Royal Meteorological Society, Vol. IV., No. 38), Chang-Wang Tu.

Exploring the Upper Atmosphere, Dorothy Fisk.

Lightning and Aircraft, G. C. Simpson.

Meteorological Results of the British Arctic Air Route Expedition, 1930-1931.

(The) Observer's Handbook, 1934. Meteorological Office.

Sunspots and Weather. Smithsonian Publication, Vol. 87, No. 18, C. G. Abbot.

World Weather Records, C. G. Simpson, Sir Gilbert Walker, R. G. Mossman, F. L. Clayton.

World Weather and Solar Activity, H. Helm Clayton.

REVIEWS

The Principles of Motor Fuel Preparation and Application

Vol. I. A. W. Nash, M.Sc., and D. A. Howes, B.Sc. Price 30/-.

This work deals with the whole subject of motor fuels from the distillation of the raw material, methods of cracking, refining, storage, hydrogenation, alcohol, etc., to the use of fuels in the cylinders of an engine and to the effects of different mixtures.

To an industry, such as aviation, whose life-blood is liquid fuel, the subject is obviously of great importance and the book contains an immense amount of information which it would be difficult to find elsewhere. Not only is almost every possible variety of fuel discussed, but such matters as latent heats, knock ratios, etc., are given, and the corrosion effects of certain fuels on metals of which tanks might be made is stated. Methanol, for instance, which has certain advantages as a fuel corrodes magnesium readily with a solution of hydrogen, though the effect is considerably slowed down when the methanol contains much ethyl alcohol or a small quantity of water. The book is full of useful notes of all descriptions, a typical instance being the note on changing from petrol to an alcohol fuel, where it is pointed out that the system must be thoroughly washed out with the alcohol mixture if trouble is to be avoided.

Another useful feature is the list of fuels sold in the various countries of the world with notes on their composition, names, and qualities. These fuels differ considerably among themselves, but contain alcohol in various proportions. There is also a name as well as a subject index and a very extensive bibliography.

The second volume will deal more directly with specifications for motor fuels, etc., and the two together should enable almost every fuel problem to be solved if a solution is possible.

The book itself is a mine of knowledge on its subject. It is arranged in a manner which facilitates reference and is an invaluable addition to any engineering library.

A Million Miles in the Air

By Captain Gordon Olley. Published by Hodder and Stoughton. Price 7/6.

Captain Olley starts his book by giving a short and rather inaccurate account of aeronautical history, and then proceeds to give an account of his own flying career, from his adventures during the war to the present day. There are a number of excellent photographs, many of which show the author in the company of persons of considerable distinction.

It is probable that Captain Olley has flown a greater distance than anyone else, and, indeed, the spectacle of a pilot who has already flown more than a million miles and is still flying regularly is impressive. If he had been driving a motor car and averaging 100 miles a day continuously it would have taken him over 27 years to attain this distance, or from the year 1905 to date. And 1905 was two years after the first man-carrying aeroplane flight was made. If those members of the general public who read this book appreciate the significance of this figure they cannot fail to be impressed with the progress of a method of transport which has made such things possible. Let it also be said, that there

are many civil pilots who are not far behind Captain Olley in the matter of miles flown.

There is little in the contents of the book which is of interest from a technical point of view, though, if it is true that the discharge of a Verey pistol is effective in frightening birds which approach too near aircraft in flight, the fact has considerable importance to those who operate aircraft in India. But the real interest of the book is that it is useful propaganda to the general public and that it would form an excellent Christmas present to those who still require information concerning the progress of aviation.

Some day, it is hoped, Captain Olley will write a book in which he will deal with his experiences from a more technical point of view. He cannot fail to have acquired an immense amount of information on operating matters which would be of great interest to those constructing commercial aircraft.

Scott's Book

By C. W. A. Scott. Published by Hodder and Stoughton. Price 7/6.

This book gives the life story of C. W. A. Scott, including a description of his successful attempts on the England-Australia record, and ends with an account of his recent victory in the MacRobertson race in company of Mr. Campbell Black. It has been written, presumably, to satisfy public curiosity about the private life and history of a man whose latest feat has brought him a considerable amount of well deserved publicity.

He learnt to fly after joining the Royal Air Force, and his experiences here do not differ materially from those of any other young officer. After leaving the Service he was engaged in commercial flying in Australia and first came into general notice when he captured the England-Australia record in April, 1931. Two other record flights between those countries followed, and then came the sensational feat of flying from Mildenhall to Melbourne in under three days.

The description given of this last flight does not differ materially from those already published in the Press, and does not elucidate one of the most interesting features of the flight, the episode of the crippled engine. We are told that, even now, neither Mr. Scott, or the mechanics who successfully got it going again at Darwin, could discover a cause for the breakdown, and one is left in doubt as to the behaviour of the engine afterwards, though it was not going, apparently, when they landed at Melbourne.

Some day, it is hoped, Mr. Scott will deal with this very notable flight from a more technical point of view and will describe his various troubles in greater detail. His accurate navigation and the methods he adopted of piloting a two-engined aeroplane with one engine only would make such a work of great technical interest.

The Internal Combustion Engine

Vol. II. D. R. Pye, Published by the Clarendon Press. Price 21/-.

In this book Mr. Pye discusses in detail a number of the special problems connected with aero engine design, and has included a chapter by Mr. Farren on aerodynamical theory so that the reader may appreciate the interconnection of the properties of the power plant with the aeroplane to which it is fitted. The matters dealt with are all discussed in a clear and lucid style, which leaves no doubt as to the meaning intended and also makes the book a pleasure to read.

The scope of the book is large, and includes chapters on the Limits of Internal Combustion Engineering, on Piston and Valve Temperatures, Lubrication and Lubricants, Principles of Heat Transference, Air-cooling of Cylinders, Liquid-cooling, Carburettors, Superchargers, Performance and Fuel Economy. All these matters are dealt with from the theoretical aspect and are exemplified with many examples drawn from actual engine tests so that the validity of the

theory may be estimated. It remains to be said that the work is admirably carried out, and it is an example of what a text book should be.

It is unfortunate that so little attention has been given to the effect of the variable pitch propeller, for, with the exception of a short reference towards the end of the work, this form of airscrew is ignored. That it must have an important influence on the design of the aero engine and that it will be fitted to most high performance aircraft in the future are matters which few will doubt, and this omission may lead to this work becoming obsolescent before its normal time. The reason for its omission is probably due to the want of experience with propellers of this type in this country. Only one slight error has been detected; on page 231, Fig. 72 has been referred to instead of Fig. 78. This fact speaks volumes for the accuracy with which the proof reading has been carried out.

The book can be recommended as a work which should be invaluable to those engaged in aero engine design, but as a great deal of what it contains is directly applicable to the design of internal combustion engines intended for other purposes, it should be of great value to the designer of the car engine, etc., who will find that much of the information given will be of great importance to him.

Richthoven, the Red Knight of the Air

By " Vigilant." Published by John Hamilton, Ltd. Price 7/6.

This book is a biography of Manfred Richthoven, possibly the most famous of all the war pilots, and certainly the best known German ace. It includes a brief history of his family and upbringing, an account of most of his more important fights, and a description of his death by a machine gun bullet in the year 1918.

Richthoven came from a family which had produced many soldiers. His early training had inured him to field sports and made him a deadly shot with a rifle and a practised horseman, than which no better foundation for the making of a fighting pilot can be found. In action he was ruthless and efficient, stalking his victim with the skill he had learnt in his Silesian deer forests. Once he had attained the position he wanted, a short burst from his guns did the rest. Probably no ace in any country obtained his results with less expenditure of ammunition. On the ground he seems to have been a stern but just disciplinarian, with a faculty for getting the best out of those under him. He spent much time in the selecting and training of the pilots under his command and taught them all he knew about air tactics. As the German authorities published the recorded victories of their pilots as they were won, the mounting of the number of his victims made him a national hero during his lifetime. Since his death a museum has been named after him, which contains many of his war trophies and personal effects.

The book suffers somewhat from defective proof reading, but is a valuable addition to war literature. It is written with the skill of a practical writer, but would be improved by the addition of an index and bibliography.

The Book of Speed

Published by B. T. Batsford, Ltd. Price 5s.

No book can deal with speed of transport without reference to aircraft, and it is therefore not surprising that some of the contributors to this publication are well known in the world of aeronautics. There is an excellent article by Captain de Havilland on " Speed in the Air," and another by Flight Lieutenant Stainforth on his record-breaking flights in the supermarine racing seaplane which is well worth reading. Colonel Etherton is not so successful in " The Dawn of Flight," for the design of the A. V. Roe triplane and of the early Blériot and Antoinette machines did not depend on the idea that metal must be

the prime factor in construction as the author states. They were wooden machines and their design was based on wood as are many of the machines of to-day. Many of the modern aeroplanes are of exactly the same type as the Blériot and Antoinette, so the type cannot be described as non-existent and neither of them, as the author suggests, had front elevators, tail outriggers, pusher propellers, nor did the pilot sit on the front edge of the lower plane. Colonel Etherton apparently believes in the future of flapping flight and quotes an experiment with a live bird in a glass wind tunnel of which it would be interesting to have further particulars.

Other contributors are Mr. Scott Pain on "Speed Boats," Captain Rostron on "Speed on the Ocean Routes," Captain Eyston on "Motor Racing," Sir Malcolm Campbell on "What it feels like," and a number of others who write with an intimate knowledge of their subjects.

The book is illustrated with a magnificent series of some 150 photographs in photogravure, which cover all the means of transport referred to. Some of the cloud effects are superb and they are alone worth the small sum asked for the book.

King of Air Fighters

By Flight-Lieut. Ian Jones, D.S.O., M.C., D.F.C. Published by Ivor Nicholson and Watson. Price 10/6.

This is a biography of Major Mannock, V.C., D.S.O., M.C., by an officer who served under his command. It is illustrated by a number of photographic portraits of war pilots, including the author and his subject.

There is no question that Major Mannock was a very notable man. The son of a corporal in the regular Army, he worked himself up by the sheer force of character and intelligence until he became one of the best known fighting pilots; and his career is a standing example of the adage that no disadvantage can hold a man down if he is determined to rise and possesses the necessary qualities. As a pilot he seems to have differed in his methods from most of the other notable fighters. Like many of them, he did not find it easy to learn to fly, and he found it still more difficult to learn to shoot, but practice overcame these disabilities and at the height of his career he was, perhaps, the best shot of all, not excepting Richthoven. He was not essentially an individualist; though, when he wished, he could go out by himself and stalk his victims with the best, but his special contribution to the science of air fighting consists in his appreciation of the importance of tactics, especially when an attack is to be made by a number of machines.

He evolved his system and methods by sheer hard thinking applied to his experience and knowledge of many tactics, and the fact that he was right was shown by the success of the squadrons under his command and by his own personal successes. He died, unconquered in the air, by a chance shot from an enemy rifleman.

Whether he was, as claimed by the author, the finest of all the war pilots, is a matter which can be left to those who served with him and with the others, but there is no question that he was surpassed by none in his skill, knowledge, and devotion to duty.

This is a book which should be read, not only by those who wish to understand more about the career of a great fighting man, but also by those who wish to study the air tactics of the last war—with a view to their application to the next.

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES

JANUARY, 1934

1934

The Council wish all members of the Society a happy and prosperous New Year.

They particularly wish to thank all members for their help during 1933. The growing membership and prestige of the Society have largely been due to the members themselves, and the Council is fully aware that, though it may initiate schemes, their success depends upon the ready co-operation of those who have elected it.

Subscriptions

Members are reminded that their subscriptions are due on January 1st, 1934. The Council hope that every member will make an effort to pay his subscription as early as possible in the new year. The rates are:—

	Home.			Abroad.		
	£	s.	d.	£	s.	d.
Fellow	4	4	0	3	0	0
Member	4	4	0	3	3	0
Associate Fellow	3	3	0	2	2	0
Associate	*2	2	0	*2	2	0
Student	1	1	0	1	1	0
Companion	2	2	0	2	2	0
Founder Member	2	2	0	2	2	0

* £1 1s. od. without Journal.

Council Meettng

A Meeting of the Council was held on Tuesday, December 12th, 1933, in the offices of the Society.

Present: Mr. C. R. Fairey (President), in the Chair, Captain P. D. Acland, Professor L. Bairstow, Major G. P. Bulman, Mr. A. H. Hall, Mr. J. E. Hodgson (Honorary Librarian), Major D. H. Kennedy (Honorary Treasurer), Mr. M. Langley, Mr. R. K. Pierson, Mr. D. R. Pye, Mr. E. F. Relf, Mr. O. E. Simmonds, Mr. L. A. Wingfield (Solicitor), Captain J. L. Pritchard (Secretary).

Among the business before the meeting was the following:—The formation of a Students' Flying Club; the Report of the Referees on the R.38 Memorial Papers; the election of Mr. Griffith Brewer and Mr. Orville Wright to Honorary Fellowship; the 1933 Award of the Daniel Guggenheim Medal; the lecture programme for the second half of the Lecture Session.

New Year Honours

In the New Year Honours' List appear the following:—

To be G.C.B.: The Rt. Hon. W. D. Weir, LL.D., D.L., *Fellow of the Society.*

To be K.C.V.O.: Sir Richard T. Glazebrook, K.C.B., *Fellow of the Society.*

To be C.B.E.: J. S. Buchanan, Esq., O.B.E., *Fellow of the Society.*

Honorary Fellows

At the Council Meeting held on Tuesday, December 12th, 1933, the Council passed a resolution recommending to the next Ordinary Meeting of members of the Society that Mr. Griffith Brewer, F.R.Ae.S., and Mr. Orville Wright, Honorary Companion, be elected Honorary Fellows of the Society. At the Ordinary Meeting of members held on Thursday, December 14th, 1933, both the recommendations of Council were unanimously approved by the members present.

Elections

The following members were elected at a Meeting of Council held on December 12th, 1933:—

Fellows.—Nevil Shute Norway, Alfred Hessell Tiltman.

Associate Fellows.—Eric Shaw, William Henry Lewis.

Associate Member.—Bernard Elliott Dunkley.

Associates.—George McCorquodale Littlejohn, Vishva Nath Puri.

Students.—Thomas Allitt, Basil Peter Brooker, Percival George Brown, William Meikle Cochran, Cyril Lancelot Fellowes Colmore, Percy Reginald Dowden, Albert Edward Draper, Archibald James Edmunds, Ivor William Jones, James Leonard Barnard Jones, Howard John Kerr, Leonard Walter Kidney, Ronald John Knights-Whittome, Cecil Thomas Locke, David Ramsay Milne, Alan Edward Richards, Allin Beddoe Stephens, Stanley Francis Titt, John Henry Van, Godfrey Bernard Vinycomb, John Denis Walsh.

Companions.—Harry Gordon Selfridge, Jun., Alexander Robert Wright.

Acknowledgments

The Council gratefully acknowledge the following:—From Mr. R. F. R. Pierce, "Charles Parsons," by Rollo Appleyard; from Ambert Villiers Air Motors, "Twenty-Five Years of Flying," by Harry Harper, "The Chemical Analysis of Iron," by A. A. Blair; from Mr. Barrington and Mr. Clarkson of the de Havilland Aircraft Company, lantern slides of various D.H. machines and engines; from Captain Norman Macmillan, several copies of the Proceedings of the Institution of Aeronautical Engineers, Notices to Airmen, etc.; from Mr. A. R. Wright, one guinea for the Endowment Fund.

R.38 Memorial Prize

Following the report of the Referees on the papers submitted for the R.38 Memorial Prize, the Council have recommended that the full prize should not be awarded this year. They further recommend that an award of £10 10s. should be made to Miss L. Chitty, A.F.R.Ae.S., for her paper entitled "Tapered Frameworks Representative of the Airship Hull."

The paper will be printed in a forthcoming issue of the JOURNAL.

The Council wish particularly to call attention to the terms of the R.38 Memorial Prize.

The prize is a sum of twenty-five guineas and it is offered for the best paper received by the Society on some subject of a technical nature in the science of aeronautics. Other things being equal, preference will be given to papers which relate to airships. It should, however, be understood that the prize is not one confined to airship papers, and the Council would welcome entries on any subject of a technical nature in the science of aeronautics.

The closing date for the receipt of papers for the next award is June 30th, 1934.

Advertising Agents

Messrs. Gale and Polden, Ltd., 2, Amen Corner, E.C.4, have been reappointed as advertising agents for the Society for the year 1934, and all inquiries with regard to advertisements should be addressed to them and not to the Editor of the JOURNAL.

International Index

An International Index to Aeronautical Technical Reports has been prepared by the Society of British Aircraft Constructors, Ltd., and is published by the Society this month at 5s. net. It consists of 132 pages bound in cloth, and is an index of British, American and Foreign Technical Reports. Specimen pages of the Index were inserted in the last issue of the Journal, and gave an indication of its scope.

It is hoped to publish the Index annually and so keep all members in touch with the latest references to reports, papers and articles of an aeronautical technical nature throughout the world. The report can be obtained from these offices, price 5s. or 5s. 4d. post free.

Aeronautical Books

Many members have suggested it would be a considerable help to them if aeronautical books could be obtained through the Society, as they often find difficulty in obtaining these books locally. The Society is in touch with most publishers of aeronautical books and books will be obtained on request.

Forthcoming Events

Tuesday, January 2nd.—Lecture before the Bristol Branch by Mr. G. O. Anderson, A.M.I.Ae.E., on "Testing of Aero Engines."

Thursday, January 4th.—Lecture before the Yeovil Branch by Flight Lieut. Nicholetts, on "The R.A.F. Long Distance Flight, 1933."

Tuesday, January 9th.—Lecture before the Manchester Branch by a Member of the Staff of Armstrong-Siddeley Motors, Limited, on "Compression Ignition Engines."

Thursday, January 11th.—Lecture before the Gloucester Branch by Mr. Handley Page, on "Slots, Interceptors, etc."

Tuesday, January 16th.—Lecture before the Northampton Town and County School, by Captain J. L. Pritchard.

Wednesday, January 17th.—Lecture before the Woolwich Polytechnic Engineering Society, by Mr. R. A. Wilmshurst.

Thursday, January 18th.—Lecture, "Ethyl," by Mr. F. R. Banks, O.B.E., F.R.Ae.S., in the Lecture Hall of the Royal Society of Arts, 18, John Street, Adelphi, W.C.2, at 6.30 p.m.

Thursday, January 18th.—Lecture before the Yeovil Branch by Mr. G. H. Field, on "Aluminium and its Alloys."

Tuesday, January 23rd.—Lecture before the Bristol Branch by Captain F. Entwistle, B.Sc., on "Meteorology."

Monday, January 29th.—Lecture before Nottingham High School, by Captain J. Laurence Pritchard.

J. LAURENCE PRITCHARD, *Secretary.*

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES

FEBRUARY, 1934

Election of Council

Attention is drawn to Rules 68-85 regulating the constitution of the Council, and in particular to Rules 79 and 81, which read as follows:—

RULE 79.—One half of the Council (excluding the President and the Immediate Past-President if a member of Council) shall retire annually. The members who shall retire shall be those longest in office, except as provided in Rule 85. Retiring members of Council who have served two terms in succession (four years) shall not be eligible for re-election until the next annual election, when they shall be eligible.

RULE 81.—Nominations of candidates for election to the Council must be received by the Secretary not less than twenty-one days before the Annual General Meeting, with an intimation in writing by the candidates that they are willing to serve. Nominations must be signed by one supporter and two seconders, who must each be entitled to vote in the R.Ae.S.I.

Under Rule 105 the Annual General Meeting is held at some convenient date before the end of March of each year, so that nominations must be received during the first week in March, and preferably by March 1st at the latest.

Council Meeting

A Meeting of Council was held on Tuesday, January 23rd, 1934, in the Offices of the Society.

Present: Mr. C. R. Fairey, President (in the Chair); Captain P. D. Acland, Major J. S. Buchanan, Major G. P. Bulman, Mr. R. S. Capon, Major D. H. Kennedy (Honorary Treasurer), Captain A. G. Lamplugh, Mr. M. Langley, Major R. H. Mayo, Mr. R. K. Pierson, Mr. D. R. Pye, Mr. E. F. Relf, and Mr. Lawrence A. Wingfield (Solicitor).

Among the business transacted was the following: Report of the Finance Committee; Report of the Grading Committee; the Wilbur Wright Lecture for 1934; election of Aerodrome Advisory Board representatives.

Associate Fellowship and Associate Membership Examination

The next Examination will be held at 7, Albemarle Street, W.1, on Friday and Saturday, March 23rd and 24th. Application forms for those desiring to take the Examination may be obtained from the Secretary, which must be returned not later than February 23rd.

Elections

The following recommendations of the Grading Committee were approved by the Council at their meeting on January 23rd, 1934:—

Associate Fellows.—William Roy Baird, Roderick Peter George Denman, Herbert Geoffrey Morcom, Sydney Clifford Robertson, Hugh Gordon Wenham.

Associate Members.—Ellis Hill, Frederick John Ott.

Associates.—John Diedrich Ahlers, Robert Charles Morgan, Mahani Narayan Sitaram.

Students.—Eric Thomas Charles Frost, Ajit Ranjan Ghosh, William Frank Hilton, John Olding Hinks, David Francis Alastair McBain, Djelal Mahmoud-Bey, Thomas Graeme Finlayson Mathers, Henry Gerald Rossiter, Alan Howard Stratford, Harold Wray Tennant.

Subscriptions

Members are reminded that their subscriptions were due on January 1st, 1934. The Society, like all other institutions, is passing through a difficult time, and the Council hope that every member will make every effort to pay his subscription as early as possible. The rates are:—

	Home.			Abroad.		
	£	s.	d.	£	s.	d.
Fellow	4	4	0	3	3	0
Member	4	4	0	3	3	0
Associate Fellow	3	3	0	2	2	0
Associate Member	3	3	0	2	2	0
Associate	*2	2	0	*2	2	0
Student	1	1	0	1	1	0
Companion	2	2	0	2	2	0
Founder Member	2	2	0	2	2	0

*£1 1s. 0d. without Journal.

Acknowledgments

The Council gratefully acknowledge the gift of a number of books for the Library from Mr. R. F. R. Pierce; the gift of One Guinea towards the Endowment Fund from Mr. A. J. Henington; and 14 photographs from the Department of Commerce, Aeronautics Branch, Washington, of U.S.A. aircraft.

Postponed Lectures

The following two lectures have been postponed:—

February 15th.—Air Commodore P. F. M. Fellowes, on "The Houston Mount Everest Flight."

April 19th.—Mr. E. F. Relf, on "Results from the Compressed Air Tunnel."

International Index

An International Index to Aeronautical Technical Reports has been prepared by the Society of British Aircraft Constructors, Ltd., and is published by the Society at 5s. net. It consists of 132 pages bound in cloth, and is an index of British, American and Foreign Technical Reports. Specimen pages of the Index were inserted in the December, 1933, issue of the Journal, and gave an indication of its scope.

It is hoped to publish the Index annually and so keep all members in touch with the latest references to reports, papers and articles of an aeronautical technical nature throughout the world. The report can be obtained from these offices, price 5s. or 5s. 4d. post free.

Aeronautical Books

Many members have suggested it would be a considerable help to them if aeronautical books could be obtained through the Society, as they often find difficulty in obtaining these books locally. The Society is in touch with most publishers of aeronautical books and books will be obtained on request.

Forthcoming Events

Thursday, February 1st.—Lecture Before Frensham Heights School, by F./O. R. E. G. Brittain.

Thursday, February 1st.—Lecture, " Engine Cowlings," by Mr. J. D. North, F.R.Ae.S., in the Lecture Hall of the Royal Society of Arts, 18, John Street, Adelphi, W.C.2, at 6.30 p.m.

Thursday, February 1st.—Lecture before the Yeovil Branch by Captain G. T. R. Hill, on " Principles of Flight."

Thursday, February 1st.—Lecture before Porlock Institute by Mr. C. T. Holmes.

Friday, February 2nd.—Lecture before Finchley Branch of Toc H, by Mr. W. E. Gray.

Monday, February 5th.—Lecture before Royal Grammar School, Worcester, by Mr. F. Radcliffe.

Monday, February 5th.—Lecture before a Manchester Society by Mr. T. Hampson.

Tuesday, February 6th.—Lecture before Rossall School, Fleetwood, by Captain J. Laurence Pritchard.

Thursday, February 8th.—Lecture before the Gloucester and Cheltenham Branch, by Mr. Devereux.

Saturday, February 10th.—Lecture before Highgate School, by Mr. W. O. Manning.

Monday, February 12th.—Lecture before St. Olave's School, by Captain J. Laurence Pritchard.

Monday, February 12th.—Lecture before the Royal Liberty School, by Mr. H. B. Walker.

Tuesday, February 13th.—Lecture before the Bristol Branch, by Professor R. V. Southwell, on " New Methods of Testing by Impact."

Tuesday, February 13th.—Lecture before the Students' Section, by Mr. R. J. Schmidt, in the Library at 7, Albemarle Street, W.1, at 7 p.m.

Thursday, February 15th.—Lecture before Blackheath High School, by Captain J. Laurence Pritchard.

Friday, February 16th.—Lecture before Leeds Grammar School, by Mr. G. C. F. Ely.

Friday, February 16th.—Lecture before Balshaw's Grammar School, by Captain J. Laurence Pritchard.

Saturday, February 17th.—Lecture before St. Peter's School, York, by Mr. G. C. F. Ely.

Wednesday, February 21st.—Lecture before the Manchester Branch, on "Flying Travel," by a member of the Staff of Imperial Airways.

Friday, February 23rd.—Lecture before the Gloucester and Cheltenham Branch, on "Soaring Flight," by Mr. C. Latimer Needham.

Saturday, February 24th.—Lecture before Hurstpierpoint College, Sussex, by Captain J. Laurence Pritchard.

Tuesday, February 27th.—Lecture before the Bristol Branch, on "Record-Breaking Engines," by Mr. R. N. Dorey.

J. Laurence Pritchard, *Secretary*.

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

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MONTHLY NOTICES

MARCH, 1934

Election of Council

Attention is drawn to Rules 68-85 regulating the constitution of the Council and in particular to Rules 79 and 81, which read as follows:—

RULE 79.—One half of the Council (excluding the President and the Immediate Past-President if a Member of Council) shall retire annually. The members who shall retire shall be those longest in office, except as provided in Rule 85. Retiring Members of Council who have served two terms in succession (four years) shall not be eligible for re-election until the next annual election, when they shall be eligible.

RULE 81.—Nominations of candidates for election to the Council must be received by the Secretary not less than twenty-one days before the Annual General Meeting, with an intimation in writing by the candidates that they are willing to serve. Nominations must be signed by one supporter and two seconders, who must each be entitled to vote in the R.Ae.S.I.

Nominations of candidates for election to the Council must be received by the Secretary on or before Tuesday, March 6th, 1934.

Annual General Meeting

The Annual General Meeting of the Society will be held in the Offices of the Society, 7, Albemarle Street, W.1, at 6.30 p.m., on Tuesday, March 27th, 1934.

Council Meeting

A Meeting of the Council was held on Tuesday, February 20th, 1934.

Present: In the Chair, Mr. C. R. Fairey, M.B.E., F.R.Ae.S., President; Captain P. D. Acland, Mr. R. S. Capon, Mr. A. H. Hall, Mr. J. E. Hodgson (Honorary Librarian), Major D. H. Kennedy (Honorary Treasurer), Mr. M. Langley, Major R. H. Mayo, Mr. D. R. Pye, Lieut.-Colonel F. C. Shelmerdine, Mr. O. E. Simmonds, Mr. L. A. Wingfield (Solicitor).

Among the business considered was the following:—The Wilbur Wright Memorial Lecture; National Air Day; the Report of the Finance Committee; the Report of the Grading Committee; the Audited Accounts of Aerial Science, Limited; the Report of the Council for the Year 1933; the Annual General Meeting; the Students' Flying Club; Professional Classes Aid Council; Air Post Exhibition.

Elections

The following recommendations of the Grading Committee were approved by the Council at their meeting on 20th February, 1934:—

Fellow.—Harold Hemming.

Associate Fellows.—Sydney Hansel, Cyril Arthur Osborn, George Cecil Rhodes, Benjamin Henry Rolles, Bernard William Shilson, Richard Walter Walker.

Associates.—Frederick Charles Cooper, Hugh Crosby.

Students.—Edward Ellis Alexander Wood, Henry Udall.

Companions.—John Godsman Brown, Mohamed Aly Fahmy, Miss Rosalind Norman.

Acknowledgments

The Council wish gratefully to acknowledge a film of the Wren light aeroplane from the designer, Mr. W. O. Manning; a series of 140 photographs of typical German aeroplanes, collected together by the German Air Ministry and forwarded through Dr. A. H. von Scherpenberg, the German Air Attaché, following a request from the Secretary; photographs of Potez aeroplanes, from Aeroplanes Henry Potez; photographs of aircraft manufactured by the Société Provençale de Constructions Aéronautiques; photographs of aircraft manufactured by Fieseler-Flugzenbau; photographs of aircraft manufactured by Avions Hanriot; photographs of " Avia 51 " manufactured by Avia Constructions Aéronautiques Société Anonyme; photographs of machines manufactured by Avions Henri et Maurice Farman; photographs of aircraft manufactured by Société Anonyme des Ateliers D'Aviation Louis Breguet; photographs of aircraft manufactured by Société Anonyme Nieuport-Astra; photographs of aircraft manufactured by Chantiers Aéro-Maritimes de la Seine; photographs of aircraft manufactured by Les Ateliers de Construction du Nord de la France et des Mureaux; photographs of " Avions Dewoitine " manufactured by Société Aéronautique Française; photographs of aircraft manufactured by Koolhoven-Vliegtuigen; photographs of aircraft manufactured by Blériot-Aéronautique; films of American machines, presented by Mr. Fred Kramer.

The Council also wish to acknowledge with grateful thanks a comprehensive set of lantern slides presented by Messrs. D. Napier and Son, Limited.

Mr. J. E. Hodgson

At a meeting of members held on February 1st, 1934, Mr. J. E. Hodgson, Honorary Librarian, was unanimously elected an Honorary Fellow of the Society in recognition of his work in the history of aviation and his work for the Society.

Visits to Canada

A letter has been received from one of the leading members of the Society in Ottawa which states that it would be of considerable assistance to the Ottawa Branch of the Society if any member of the Society, who is visiting Canada, would give the branch as long notice of their visit as possible, so that the necessary arrangements can be made for a meeting if possible. The Canadian Branches would particularly appreciate any talk, informal or otherwise, from members of the Society when in Canada.

Light Aeroplane Experiments

The following letter has been received from Poland. If interested members wish to communicate with the Students mentioned, the Secretary will be happy to forward letters:—

> " . . . The British Vice-Consul at Katowice has been approached by Students of a Technical School who are experimenting with light aeroplanes propelled by means of a motor-cycle engine. It is believed that similar experiments are being made in the United Kingdom, and if so, they are most anxious to exchange drawings and experimental results with persons engaged in such work whom they believe to be also students."

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Aeronautical Books

Many members have suggested it would be a considerable help to them if aeronautical books could be obtained through the Society, as they often find difficulty in obtaining these books locally. The Society is in touch with most publishers of aeronautical books and books will be obtained on request.

Information Wanted.

In the January issue of the Journal, Mr. W. O. Manning, in his article " Fifty Years Ago," drew attention to an aerial machine which was tested by a Mr. Linfield behind a Great Western locomotive between West Drayton and Staines, on August 29th, 1883. If any member of the Society has any information about this experiment, described in some detail in Mr. Manning's article, will he send particulars to the Secretary?

Obituary

The Council greatly regret to record the death of Flight Lieut. R. E. H. Allen, who was an Associate Member of the Society from 1923. He will be very much missed as he was an indefatigable helper in the work of the Society whenever the opportunity occurred. Among the ways in which he helped was in giving Schools Lectures under the auspices of the Society from time to time.

Forthcoming Events

Thursday, March 1st.—Lecture, " Speed and the Economics of Air Transport," by Major F. M. Green, O.B.E., M.Inst.C.E., F.R.Ae.S., in the Lecture Hall of the Royal Society of Arts, 18, John Street, Adelphi, W.C.2, at 6.30 p.m.

Thursday, March 1st.—Lecture before the Westland Aircraft Society (Yeovil Branch), by Mr. E. F. Relf, F.R.Ae.S.

Friday, March 2nd.—Lecture before Eccles Secondary School, by Mr. T. Hampson.

Tuesday, March 6th.—Joint Lecture with the Institution of Automobile Engineers and Other Bodies. "The Relation of the Molecular Structure of Fuels to their Behaviour in Diesel Engines," by Mr. G. D. Boerlage, M.E., and Dr. W. J. D. Van Dyck, at the Royal Geographical Society, South Kensington, at 7.30 p.m.

Tuesday, March 6th.—Lecture before Epsom College, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

Thursday, March 8th.—Lecture before the Cheltenham Branch by Mr. W. Hackett, on "Tubes."

Saturday, March 10th.—Lecture before Eastbourne College by Mr. S. Scott Hall, A.C.G.I., M.Sc., D.I.C., A.F.R.Ae.S.

Thursday, March 15th.—Lecture, "Some Developments in Aircraft Construction," by Mr. H. J. Pollard, Wh. Ex., A.F.R.Ae.S., in the Lecture Hall of the Royal Society of Arts, 18, John Street, Adelphi, W.C.2, at 6.30 p.m.

Thursday, March 22nd.—Lecture before the Manchester Branch.

Friday, March 23rd.—Associate Fellowship and Associate Membership Examinations, at 7, Albemarle Street, W.1.

Saturday, March 24th.—Associate Fellowship and Associate Membership Examinations, at 7, Albemarle Street, W.1.

Tuesday, March 27th.—ANNUAL GENERAL MEETING of the Society at 6.30 p.m. in the Offices of the Society.

J. LAURENCE PRITCHARD, *Secretary.*

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES

APRIL, 1934

Council, 1934-35

There were ten vacancies for the Council in March and ten nominations, so that no election was necessary. The following is the Council for 1934-35. Newly elected members are marked with an asterisk:—

President:

Mr. C. R. Fairey, M.B.E., F.R.Ae.S.

Past-President:

Lord Sempill, A.F.C., F.R.Ae.S.

Council:

Captain P. D. Acland.
Major J. S. Buchanan, C.B.E., F.R.Ae.S.
Major G. P. Bulman, O.B.E., F.R.Ae.S.
Mr. R. S. Capon, O.B.E., F.R.Ae.S.
Mr. E. C. Gordon England, F.R.Ae.S.
Mr. A. H. Hall, C.B.E., F.R.Ae.S.
*Mr. S. Scott Hall, A.C.G.I., M.Sc., D.I.C., A.F.R.Ae.S.
*Mr. F. T. Hill, F.R.Ae.S., M.I.Ae.E.
Captain A. G. Lamplugh, F.R.G.S., F.R.Ae.S., M.I.Ae.E.
Mr. M. Langley, A.M.I.Ae.E., A.M.Inst.N.A.
*Mr. W. O. Manning, F.R.Ae.S.
Major R. H. Mayo, O.B.E., F.R.Ae.S.
*Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., M.P., F.R.Ae.S.
Mr. D. R. Pye, M.A., F.R.Ae.S.
Mr. E. F. Relf, A.R.C.S., F.R.Ae.S.
*Mr. W. P. Savage, A.F.R.Ae.S.
Lieut.-Colonel F. C. Shelmerdine, C.I.E., A.F.R.Ae.S.
Sir J. D. Siddeley, C.B.E., F.R.Ae.S.
Mr. F. Sigrist, M.B.E., F.R.Ae.S.
Mr. O. E. Simmonds, M.A., M.P., F.R.Ae.S., M.I.Ae.E.
*Mr. H. E. Wimperis, C.B.E., M.A., F.R.Ae.S.

Hon. Treasurer:

Major D. H. Kennedy, O.B.E., F.R.Ae.S.

Solicitor:

Mr. Lawrence A. Wingfield, M.C., D.F.C., A.R.Ae.S.I.

Hon. Librarian:

Mr. J. E. Hodgson, Hon. F.R.Ae.S.

Hon. Accountant:

A. N. D. Smith, Esq., F.C.A.

Secretary and Editor:

Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

Wilbur Wright Memorial Lecture

The 22nd Wilbur Wright Memorial Lecture will be delivered by Professor B. Melvill Jones, A.F.C., M.A., F.R.Ae.S., on Thursday, May 31st, at the Science Museum, South Kensington, S.W.7. The lecture will be followed by a Conversazione, further details of which will appear in the May Journal.

Conversazione

For a number of years the Council were fortunate in obtaining the permission of the Director of the Science Museum to hold there, annually, the Wilbur Wright Memorial Lecture, followed by a Conversazione.

Following the 1932 Lecture and Conversazione a member raised the point that no member was able to attend the Wilbur Wright Memorial Lecture without also being present at the Conversazione, for which a charge of 5s. was made. The Council decided, therefore, in 1933 that the Wilbur Wright Memorial Lecture should be held apart from the annual Conversazione, and they were fortunate in obtaining permission to hold the lecture in the Lecture Theatre of the Royal Institution. The result can only be described as a complete failure. At the most important lecture of the Society's year, held in the building of a famous institution, less than 100 members attended. Many members intimated to the Council that they would welcome the return to holding the Wilbur Wright Memorial Lecture and the Conversazione together. This year, therefore, the combined function will be held at the Science Museum as in previous years, when attendances have been between 300 and 400.

The Council feel that an evening devoted to the reading of the lecture and followed by a reception of those present by the President and Council to a conversazione is one which is welcomed by the great majority of members of the Society. The function is held in ideal surroundings and is one which enables members and their friends to gather together in a way which is not possible normally.

The Council would particularly like to draw the attention of the members to the fact that the charge at present made does not cover the cost involved. There is a loss on the evening of normally between £120-£140. This loss is one which the Society itself cannot afford, and it has been generously defrayed by the President in past years.

Council Meeting

A Meeting of Council was held on Tuesday, March 13th, 1934, in the Offices of the Society.

Present: Mr. C. R. Fairey (President) in the chair; Captain P. D. Acland, Air Marshal Sir H. R. M. Brooke-Popham (Vice-President), Major J. S. Buchanan, Mr. R. S. Capon, Mr. E. C. Gordon England, Mr. A. H. Hall, Mr. J. E. Hodgson (Honorary Librarian), Mr. M. Langley, Major R. H. Mayo, Mr. R. K. Pierson, Mr. D. R. Pye, Mr. E. F. Relf, Lieut.-Colonel F. C. Shelmerdine, Mr. O. E. Simmonds, Mr. L. A. Wingfield (Solicitor).

Among the business transacted was the following:—The Report of the Grading Committee; Chairmen for forthcoming lectures; consideration of new premises for the Society.

Elections

The following recommendations of the Grading Committee were approved by the Council at their meeting on March 13th, 1934:—

Fellow.—Miss Letitia Chitty.

Associate Members.—William Roy Baird, Harry Ledger.

Associates.—Captain the Earl Amherst, Hendrik Alexander Seyffardt.

Students.—Norman Weston Henrig, Harold Kember.

Companions.—John Lawrence Edwardes, Ambrosius Daniel Khan, Humphrey Charles Willis.

Subscriptions

Under the Rules, members who have not paid their subscriptions for the current year by April 1st are not entitled to have the Journal sent to them. It is not always possible to send back numbers of the Journal to those who pay their subscriptions some time after April 1st, as many of the Journals go out of print.

The Council wish to thank all those members who have been prompt in paying their subscriptions. By the members supporting the Society in this way it is possible to legislate ahead and make arrangements which effect considerable saving against having to work from month to month.

Acknowledgments

The Council gratefully acknowledge the following:—From Mr. F. M. Walsh, complete set of the Journal for 1933; from Mr. Howard Flanders, the Journal for June, 1933, and February, 1934, R.100 Pamphlet, Catalogue of the Rheims Meeting, August, 1909, and Mr. Trois Grandes Courses par André Beaumont, Journal of the Institution of Aeronautical Engineers, Vol. I, No. 3; from Dr. A. F. Zahm, Bibliography on Skin Friction and Boundary Flow, and eight pamphlets by himself on various topics in aerodynamics; from M. Jean Pontremoli, La Détonation et quelques Problèmes qu'elle pose, vus par le Constructeur de Moteurs; from Dr. Ing. Luigi Stipa, photographs of the Stipa-Caproni experimental aeroplane; from De Havilland Aircraft Co., Ltd., three photographs of the D.H. 86; from Société Industrielle d'Aviation Latécoère, photographs of their aircraft; from Louis du Rivau, photographs of aeroplanes; from Colonel E. Mossberg, Swedish Air Attaché, photographs of Swedish Aircraft; from Aero Tovarna Letadel Praha-Vysocany, photographs of aeroplanes; from Podlaska Wytwornia Samolotow, photographs of aeroplanes.

The Council also desire to gratefully acknowledge the sum of one guinea for the Endowment Fund from Mr. J. W. C. Logan for the second year in succession.

Forthcoming Events

Thursday, April 5th.—Lecture before the Cheltenham Branch, by Mr. A. H. R. Fedden, on "Engine Development."

Tuesday, April 10th.—Meeting of Council in the Library at 7, Albemarle Street, W.1.

Thursday, April 12th.—Lecture, "Speed and the Future of Commercial Aircraft," by Monsieur Louis Breguet, in the Lecture Hall of the Royal Society of Arts, 18, John Street, Adelphi, W.C.2.

Thursday, April 19th.—Lecture, "The Houston Mount Everest Flight," by Air Commodore P. F. M. Fellowes, in the Lecture Hall of the Royal Society of Arts, 18, John Street, Adelphi, W.C.2.

Thursday, April 26th.—Lecture, "Landing in Fog," by Dr. Rüd. Stüssel, in the Lecture Hall of the Royal Society of Arts, 18, John Street, Adelphi, W.C.2.

J. LAURENCE PRITCHARD, *Secretary.*

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES

MAY, 1934

Associate Fellowship and Associate Membership Examinations

Examinations for Associate Fellowship and Associate Membership were held in the Offices of the Society on March 23rd and March 24th, 1934. The following have satisfied the examiners in their respective subjects:—

ASSOCIATE FELLOWSHIP.

Strength of Materials and Theory of Structures.—W. Baillie, D. F. Horne, J. G. H. Pardoe, P. R. Poole, R. M. A. Rice, D. R. Sherwin, J. W. Sutcliffe, A. S. M. Wedderburn.

Applied Mathematics.—W. Baillie, D. Bamford, N. B. Berrington, A. H. Denny, D. F. Horne, J. G. H. Pardoe, R. M. A. Rice, J. W. Sutcliffe, A. S. M. Wedderburn, C. P. L. Nicholson.

Theory of Internal Combustion Engines.—W. Baillie, A. E. C. Carter, A. H. Denny, D. F. Horne, W. L. M. Denny, J. G. H. Pardoe, R. M. A. Rice, D. R. Sherwin, J. W. Sutcliffe, A. S. M. Wedderburn, N. R. Rustomjee.

Pure Mathematics.—P. R. Poole, N. R. Rustomjee.

Aerodynamics.—P. R. Poole.

Air Transport.—N. R. Rustomjee.

ASSOCIATE MEMBERSHIP.

Strength of Materials and Theory of Structures.—A. J. Cope, C. England, M. M. Prosser, G. W. Topping, H. Walker.

Applied Mathematics.—A. J. Cope, C. England, G. W. Topping.

Pure Mathematics.—H. Walker.

Theory of Internal Combustion Engines.—A. J. Cope, G. W. Topping.

Design (Aircraft).—H. Walker.

Wilbur Wright Memorial Lecture

Members are reminded that the 22nd Wilbur Wright Memorial Lecture, by Professor B. Melvill Jones, A.F.C., M.A., F.R.Ae.S., on "Stalling," will be held at the Science Museum, South Kensington, on Thursday, May 31st, at 9.15 p.m., to be followed by a Conversazione. A Reception of Members and their guests will be held by the President and the Council. The lecture will be illustrated with a special film and slides.

Conversazione

On Thursday, May 31st, 1934, the Society will hold a Conversazione to mark the end of the Session. By kind permission of the Director, Colonel E. E. B. Mackintosh, D.S.O., the Conversazione will be held in the Science Museum, Aeronautical Section, South Kensington, in the immediate neighbourhood of the many historic aircraft which are housed there, the Wright Machine,

the first power-driven controlled aircraft to fly; the Vickers Vimy which made the first crossing of the Atlantic in 1919; and many others.

The programme for the evening is approximately as follows:—

8.30 p.m.—9.0 p.m.—Reception by the President, Mr. C. R. Fairey, M.B.E., F.R.Ae.S., and the Members of Council.

9.15 p.m.—10.0 p.m.—Delivery of the 22nd Wilbur Wright Memorial Lecture by Professor B. Melvill Jones, A.F.C., M.A., F.R.Ae.S., on "Stalling."

10.0 p.m.—midnight.—Conversazione.

There will be a Buffet at which Members and their guests will be able to obtain refreshments, the cost of which is included in that of their tickets. The Conversazione enables Members and their friends to meet in unique surroundings, and the President and Council hope that every Member of the Society will make a special effort to attend what is the chief function of the Society's year and make it outstandingly successful. Ladies are specially invited to be present as well as non-members. During the evening the band of the Royal Air Force will play.

Tickets for the Reception, Lecture and Conversazione (including buffet) are 5/- each, and early application should be made.

Council Meeting

A Meeting of Council was held in the Offices of the Society on Tuesday, April 10th, 1934.

Present:—Mr. C. R. Fairey (President) in the chair; Captain P. D. Acland, Mr. E. C. Gordon England, Mr. A. H. Hall, Mr. S. Scott Hall, Captain F. T. Hill, Major D. H. Kennedy (Honorary Treasurer), Captain A. G. Lamplugh, Mr. M. Langley, Mr. W. O. Manning, Major R. H. Mayo, Mr. D. R. Pye, Mr. W. P. Savage, Mr. O. E. Simmonds, Mr. H. E. Wimperis, Mr. L. A. Wingfield (Solicitor).

Among the business transacted was the following:—The Report of the Finance Committee; the Report of the Grading Committee; training scheme of H.M.S. "Worcester"; terms of awards for the various prizes; the Resolution of the Annual General Meeting with regard to the Rules of the Society; appointment of Committees of Council; appointment of representatives on other bodies; appointment of representatives to attend the dinner of the Air Committee of the House of Commons.

Elections

The following recommendations of the Grading Committee were approved by the Council at their meeting on April 10th, 1934:—

Associate Fellows.—Henry Frederick Vulliamy Battle, Miss Frances Beatrice Bradfield, Frank Beeton Ford, Frank Gill, Teny Kumpera, Gwilym James Richards.

Associates.—Francis Thomas Bradley, Ronald Denton-Samuel, Charles Exton Gardner.

Lecture Suggestions

In May and June the Council and the Lectures Committee consider the Programme of Lectures for the coming Session. The Council will be very glad to receive suggestions for lectures and will always give them very special consideration, as every effort is made each year to present a programme of lectures which will cover as wide a range as possible and be as helpful as possible. Suggestions should be received immediately.

Junior Institution of Engineers

On June 27th, 28th and 29th, the Junior Institution of Engineers are celebrating their Jubilee. The Institution would be very glad to hear from any of its old members on this occasion who might wish to have an opportunity to share in the special activities during the period of the celebrations. Full particulars may be obtained direct from the Secretary, 39, Victoria Street, Westminster, S.W.1.

Empire Air Day

May 24th will be Empire Air Day. It has been organised by the Air League of the British Empire, and arrangements have been made for all those who wish to have an opportunity that day of seeing aviation from the inside.

A large number of flying clubs will make special arrangements on that day for the public to be allowed to visit their hangars and workshops and witness demonstrations of flying and training of pilots and have the opportunity of flying.

Nearly 50 Royal Air Force stations throughout the country will be open from 2 to 7 p.m. to public inspection. All branches of R.A.F. activity are included, and the ordinary routine training of each station will be carried out on May 24th, so that those who wish will be given a chance of seeing at first hand what such training work is. Guides will explain all that is to be seen and it will be possible to inspect aircraft and their equipment and to visit quarters and institutes.

Full particulars of the arrangements in any particular district may be obtained direct from the Secretary of the Air League of the British Empire, 19, Berkeley Street, London, W.1.

Acknowledgments

The Council gratefully acknowledge from Mr. W. O. Manning, Fellow, a copy of "Animal Flight," by Dr. Hankin, and "Technical Electricity," by Davidge and Hutchinson; also copies of the Journal from Mrs. John Fullerton, Mr. R. F. R. Pierce and Mr. Thurstan James. They also wish to acknowledge the presentation of photographs from the following firms:—General Aviation Manufacturing Corporation, U.S.A.; Kellett Autogiro Corporation, U.S.A.; The Beech Aircraft Company, U.S.A.; Boeing Airplane Company, U.S.A.; Northrop Corporation, U.S.A.; The Waco Aircraft Company, U.S.A.; The Pennsylvania Aircraft Syndicate, Limited, U.S.A.; Aktiebolaget Svenska Jarnvagsverkstaderna, Sweden; Junkers-Werke, Germany.

Forthcoming Arrangements

Tuesday, May 15th.—Lecture before the Students' Section on "Aircraft Radio Introductory," by Mr. D. Hay Surgeoner. Mr. R. P. G. Denman, Associate Fellow, in the chair. In the Library of the Society at 7.0 p.m.

Thursday, May 24th.—Lecture before Bishop Road Higher Institute, Bristol, on "The Uses of the Aeroplane," by Mr. W. Brierley, Associate Fellow.

Thursday, May 31st.—Twenty-second Wilbur Wright Memorial Lecture, by Professor B. Melvill Jones, Fellow, on "Stalling." At the Science Museum, to be followed by a Conversazione.

J. LAURENCE PRITCHARD, *Secretary.*

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES

JUNE, 1934

Council Meeting

A Meeting of Council was held on Tuesday, May 8th, 1934, in the Offices of the Society.

Present: Mr. C. R. Fairey (President) in the chair. Captain P. D. Acland, Mr. E. C. Gordon England, Mr. S. Scott-Hall, Mr. F. T. Hill, Mr. J. E. Hodgson (Honorary Librarian), Major D. H. Kennedy (Honorary Treasurer), Captain A. G. Lamplugh, Mr. M. Langley, Mr. W. O. Manning, Major R. H. Mayo, Lieut.-Colonel J. T. C. Moore-Brabazon, Mr. D. R. Pye, Mr. E. F. Relf, Lord Sempill, Lieut.-Colonel F. C. Shelmerdine, Mr. F. Sigrist, Mr. L. A. Wingfield (Solicitor).

Among the matters under discussion were the following:—Report of the Finance Committee; Report of the Grading Committee; Report of the Lectures Committee; Report of the Medals and Awards Committee; nominations and election of President; nomination and election of Vice-Presidents; proposed Charter for the Guild of Air Pilots.

President

Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.I.Ae.E., M.P., was elected President of the Society for the year 1934-1935 at the Council Meeting held on May 8th, 1934.

Vice-Presidents

The following were elected Vice-Presidents of the Society for the year 1934-1935, at the Council Meeting held on May 8th, 1934:—

Mr. H. E. Wimperis, C.B.E., F.R.Ae.S.
Sir John Siddeley, C.B.E., F.R.Ae.S.

Elections

The following recommendations of the Grading Committee were approved by the Council at their meeting on May 8th:—

Associate Fellows.—Wilfrid Barnard, Walter Frederick Dowsett, Frank Whittle.

Associates.—John Burt Flynn, Reginald Thomas Wood.

Associate Members.—Henry John William Coward, Cyril Donovan Tong.

Students.—Herbert George Kimber, Jamshed Earchshaw Shroff, George Richard Williams.

Companions.—Walter Noel Ash, Francis Robert Benjamin King, Cyril William Lawson.

International Index

An International Index to Aeronautical Technical Reports has been prepared by the Society of British Aircraft Constructors, Ltd., and is published by the Society at 5s. net. It consists of 132 pages bound in cloth, and is an index of British, American and Foreign Technical Reports. Specimen pages of the Index were inserted in the December, 1933, issue of the Journal, and gave an indication of its scope.

It is hoped to publish the Index annually and so keep all members in touch with the latest references to reports, papers and articles of an aeronautical technical nature throughout the world. The report can be obtained from these offices, price 5s. or 5s. 4d. post free.

Acknowledgments

The Council gratefully acknowledge the presentation of photographs from the Glenn L. Martin Company, the Sikorsky Aviation Corporation and Amphibions Incorporated. They also desire to acknowledge the return of Journals for a number of years from Mr. P. T. Griffith, Associate Fellow; from Captain Keith Davies, Associate Fellow, rare historical notices of the first flight in India; and from Mr. J. E. Raddings three slides of the Radlock glider.

Awards

The following awards were made at a Meeting of the Medals and Awards Committee on May 1st, 1934:—

British Gold Medal for Aeronautics.—Captain Geoffrey de Havilland, O.B.E., A.F.C., F.R.Ae.S.

Simms Gold Medal.—Sir Gilbert Walker, Kt., C.S.I., F.R.A.S., Sc.D., F.R.S., Ph.D., M.A.

Taylor Gold Medal.—Mr. A. Plesman.

Wakefield Gold Medal.—Senor Juan de la Cierva, F.R.Ae.S.

Busk Memorial Prize.—Mr. A. V. Stephens, B.A.

Pilcher Memorial Prize.—Mr. W. H. Lewis, B.Sc., A.C.G.I., A.F.R.Ae.S.

J. Laurence Pritchard, *Secretary.*

THE

ROYAL AERONAUTICAL SOCIETY

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MONTHLY NOTICES

JULY, 1934

August Bank Holiday

The Offices of the Society will be closed from Saturday, August 4th, to Monday, August 6th, inclusive.

British Gold Medal for Aeronautics

The Amulree Committee have unanimously awarded the British Gold Medal for Aeronautics to Captain G. de Havilland for his many achievements leading to advancements in aeronautical science.

King's Birthday Honours

Viscount.—Lord Wakefield of Hythe, C.B.E., an Honorary Fellow of the Society.

C.B.E.—Captain Geoffrey de Havilland, a Fellow of the Society.

Council Meeting

A Meeting of Council was held in the Offices of the Society on Tuesday, June 12th, 1934.

Present:—Lieut.-Colonel J. T. C. Moore-Brabazon (President-Elect) in the chair; Captain P. D. Acland, Major J. S. Buchanan, Mr. R. S. Capon, Mr. A. H. Hall, Mr. F. T. Hill, Major D. H. Kennedy (Honorary Treasurer), Mr. M. Langley, Mr. W. O. Manning, Mr. D. R. Pye, Mr. E. F. Relf, Sir John Siddeley, Mr. O. E. Simmonds, Mr. L. A. Wingfield (Solicitor).

Among the business transacted was the following:—The Report of the Grading Committee; the Report of the Finance Committee; the Appointment of a Rules Committee; the Lecture Programme for next Session; the proposed Charter for the Guild of Air Pilots; Informal Meetings for members.

Public Schools' Lectures

The Council are arranging for the fourth year in succession to give lectures before the Public Schools and other educational establishments. The success of these lectures depends largely upon the very willing help which members of the Society have given by undertaking to deliver a lecture to one of the schools.

As most members know, these lectures are arranged to give the minimum amount of trouble to the lecturer. Each lecture has about 40-50 slides and the lecture itself is written round the slides.

The Council hope that this year, as in the past, members will volunteer to give one of these lectures and will get in touch with the Secretary as early as possible. Where it is possible the preference of a member for any particular school or district will be observed. The following is a list of the lectures:—

1. The History of the Aeroplane.
2. The Aeroplane and its Uses.
3. Seaplanes and Flying Boats.
4. Training Royal Air Force Pilots.
5. How Aeroplanes are Built and Fly.

Handbook of Aeronautics

The new edition of the Handbook of Aeronautics is published this month in two volumes. It has been greatly enlarged and re-set and brought up-to-date. The first volume contains sections on Aerodynamics, Performance, Construction, Materials, Meteorology, Instruments, Wireless, Air Survey and Photography, Design Data and Formulæ, Design and Construction of Gliders and Sailplanes and general tables. The second volume is concerned entirely with aero engines and airscrews. It is in itself an up-to-date treatise on aero engine design and practice as the following chapter headings show:—Design data; performance data; design and stress calculations; supercharging; carburettors and intake systems; cooling; ignition; fuels and fuel systems; lubricating oils and oil systems; exhaust systems and silencing; engine heaters and starting; testing of engines; compression ignition engines; and airscrews.

Both volumes may be obtained from the Offices of the Society. Vol. I, 25/- net, and Vol. II, 15/- net.

Visits

A Students' Visit has been arranged to the Royal Aircraft Establishment on Saturday, July 14th. Students who wish to attend to write to Mr. G. L. H. Bott, Hon. Secretary of the Students' Section, before Saturday, July 7th.

Elections

The following recommendations of the Grading Committee were approved by the Council at their meeting on June 12th, 1934:—

Member.—Marcus Langley (from Associate Member).

Associate Fellows.—Charles Chapleo, Arthur George Bradford Metcalf.

Associates.—Francis John Hopgood, William James Williams.

Students.—Edward John Gregson, Harold Murphy, Jan Daniel Jacobus de Necker.

Acknowledgments

The Council gratefully acknowledge a set of back numbers of the Journal from Mr. R. McKinnon Wood, Fellow.

Illustrations

The Council wish to acknowledge the loan of blocks from *Aircraft Engineering* to illustrate the paper by Mr. North and that on Cowling and Cooling of Radial Air-Cooled Engines.

J. Laurence Pritchard, *Secretary.*

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES

AUGUST, 1934

The Offices of the Society will be closed from Saturday, August 4th, to Monday, August 6th, inclusive.

International Index

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The cost of preparing and publishing such an index is heavy, and it can only be published at regular intervals if there is a demand for it. It is hoped that every member will support this index, as it brings their information continually up-to-date from the reports, papers and articles of an aeronautical technical nature throughout the world. The report can be obtained from these Offices, price 5s., or 5s. 4d. post free.

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Both volumes may be obtained from the Offices of the Society. Vol. I, 25/- net, and Vol. II, 15/- net.

Elliott Memorial Prize

The Elliott Memorial Prize has been awarded to Leading Aircraft Apprentice V. C. Darling, at Halton.

Bound Copies of "Flight"

The Society has for disposal the following duplicate bound numbers of "Flight," and would be glad to hear of any members desiring to complete their

sets: Volume I, 1909; Volume II, 1910 (two bound copies); 1912 (July-December); 1915 (January-June); 1918 (July-December).

Acknowledgments

The Council have to acknowledge with thanks the receipt of 12s. 6d. towards the funds of the Society from Mr. L. S. Ash. They would also like to acknowledge with thanks the receipt of photographs from the Bellanca Company, and a number of programmes of early flying meetings, catalogues and books, of historic interest, from Mr. C. G. Grey.

Associate Fellowship and Associate Membership Examinations

The next examination will be held in the offices of the Society on October 2nd and 3rd. Intending candidates must send in their entry forms by August 14th at the latest.

J. Laurence Pritchard, *Secretary.*

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

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MONTHLY NOTICES

SEPTEMBER, 1934

Lecture Programme

The following lectures have been arranged for the first half of the 1934-35 Session :—

Thursday, 18th October.—Professor A. J. Sutton Pippard, F.R.Ae.S., " The Education of Aeronautical Engineers."

Thursday, 25th October.—Mr. E. F. Relf, A.R.C.Sc., F.R.Ae.S., " The Compressed Air Tunnel."

Thursday, 8th November.—M. Louis Breguet, " Speeds of Commercial Aircraft."

Thursday, 15th November.—Mr. I. I. Sikorsky, " Flying Boats."

Thursday, 22nd November.—Professor Dr. Wilhelm Schmidt, " Air Turbulence near the Ground."

Thursday, 29th November.—Captain A. G. Forsyth, " Engine Research."

Thursday, 6th December.—Senor Juan de la Cierva, F.R.Ae.S., " Recent Progress of the Autogiro."

Thursday, 13th December.—Dr. W. H. Hatfield, A.F.R.Ae.S., " Recent Research in Metallurgy."

Air Marshal Balbo has agreed to lecture on his Atlantic Flight on a date which will be announced as soon as possible.

Library

The Library will be closed to members on October 2nd and 3rd, while the Associate Fellowship and Associate Membership Examinations are in progress.

Acknowledgments

The Council wish gratefully to acknowledge on loan a remarkable collection of modern technical German books, papers, pamphlets, etc., from Mr. E. C. Bowyer, Head of the Information Department of the Society of British Aircraft Constructors. This collection is one of the finest which has been gathered together and will form a most useful and necessary addition to the library of the Society. The Council also wish to acknowledge a collection of aeronautical pamphlets from Mr. H. R. Trost for the Society's collection.

International Index

An International Index to Aeronautical Technical Reports has been prepared by the Society of British Aircraft Constructors, Ltd., and is published by the

Society at 5s. Net. It consists of 132 pages bound in cloth, and is an index of British, American and foreign technical reports.

The cost of preparing and publishing such an index is heavy, and it can only be published at regular intervals if there is a demand for it. It is hoped that every member will support this index, as it brings their information continually up-to-date from the reports, papers and articles of an aeronautical technical nature throughout the world. The report can be obtained from these Offices, price 5s., or 5s. 4d. post free.

J. LAURENCE PRITCHARD, *Secretary*.

OBITUARY

HERMANN GLAUERT, F.R.S., *Fellow*.

The Council greatly regret to record the death of Hermann Glauert, a Fellow of the Society.

Mr. Glauert was struck and fatally injured by a flying fragment of wood while watching engineers blowing up the stump of a tree on Fleet Common, Hampshire, on August 4th, 1934.

Hermann Glauert was born in Sheffield on October 4th, 1892, and was the son of Mr. Louis Glauert. He was educated at King Edward VII School, Sheffield, and Trinity College, Cambridge, where he took a first class in the Mathematical Tripos, Part I, in 1911, and Part II in 1913. In the latter year he was awarded the Tyson medal for astronomy and related subjects. In the following year he was awarded the Isaac Newton Studentship in astronomy and physical optics and the Rayleigh prize for mathematics in 1915. He joined the staff of the Royal Aircraft Establishment in 1916, where he was engaged on aerodynamical research until his death, and in 1920 was elected a Fellow of Trinity and recently a Fellow of the Royal Society. He was elected a Fellow of the Royal Aeronautical Society in 1926.

Hermann Glauert made many important contributions to the science of aerodynamics. He was the author of numerous Reports and Memoranda of the Aeronautical Research Committee dealing with aerofoil and airscrew theory, performance, stability and control of aeroplanes, and the theory of the autogiro. His work, "The Elements of Aerofoil and Airscrew Theory," published in 1926, is a standard work on the subject. He contributed numerous papers in the Proceedings of the Royal Society and lectured before the Royal Aeronautical Society.

In 1922 he married Muriel Barker, B.Sc., and leaves two sons and a daughter, to whom the President and Council extend their deepest sympathy in her tragically swift bereavement.

The following appreciation of Mr. Glauert and his work from Mr. H. E. Wimperis, Director of Scientific Research, appeared in *The Times*:—

"The sudden death of Mr. Glauert is a serious loss to aeronautical science. As a Fellow of the Royal Society and a fellow of Trinity College, Cambridge, he was one of the chief of the research workers of the Air Ministry. His mathematical work in the field of aeronautics had won for him an international reputation, and he was this year appointed as head of the Aerodynamics Department of the Royal Aircraft Establishment at Farnborough. He was prominent, not only as the leader of a team of scientific workers, but as having made personal contributions of the highest value. Such men are rare and almost irreplaceable. His sudden death is a serious blow to his scientific friends and collaborators."

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

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MONTHLY NOTICES

OCTOBER, 1934

Lectures

The inaugural lecture will be held on Thursday, October 18th. The lecture, "The Education of Aeronautical Engineers," by Professor A. J. Sutton Pippard, F.R.Ae.S., is one of great importance and the Council are anxious that as many members as possible will attend to take part in the discussion. The correct training of the aeronautical engineer is still a matter of considerable diversity of opinion, and the Council are anxious, for that reason, to obtain as many views as possible, as the Royal Aeronautical Society ultimately must give a lead in the matter.

The occasion of the lecture will also be taken as an opportunity to inaugurate the new President, Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.P.

Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.P.

Lieut.-Colonel J. T. C. Moore-Brabazon, M.C., F.R.Ae.S., M.P., President-elect of the Society, will be inaugurated at the opening meeting of the 1934-35 Session of the Society on October 18th, 1934.

Lieut.-Colonel J. T. C. Moore-Brabazon holds No. 1 Royal Aero Club pilot's certificate and was the first English pilot to fly. He won the *Daily Mail* £1,000 prize for flying a circular mile in 1909 and was the first winner of the Empire British Michelin Cup. He was in the R.F.C. during the war and a member of the original Civil Aviation Committee. He became Parliamentary Secretary to Rt. Hon. Winston Churchill, the Secretary of State for Air, 1923; Parliamentary Secretary, Ministry of Transport, 1923-24, 1924-27; Chairman of the Air Mail Committee, 1923; has been Chairman of the Royal Aero Club; President of the Institution of Aeronautical Engineers, before its amalgamation with the Society; he was appointed Assessor at the R.101 inquiry, 1930-31; and is at present a Member of Parliament and member of a number of aviation committees.

Mr. C. R. Fairey, M.B.E., F.R.Ae.S.

The retiring President, Mr. C. R. Fairey, M.B.E., F.R.Ae.S., has served four years, being specially re-elected in 1932 following the suspension of the Rule that a President may not serve for more than two years.

Mr. Fairey has served during one of the most difficult periods in the Society's history, a period of considerable financial difficulty, and one in which the great majority of societies have had definite set-backs in their membership. It is due to the wise guidance of the President that the Society during those years has continued to progress and to add to its membership. He has put the Society

foremost during the whole of his period of office, has worked continuously on its behalf, and it is largely due to his own personal efforts that many important decisions of Council have been brought to successful conclusions. It is undoubtedly due to his influence, indeed, that the Society is playing an increasingly important part in aviation affairs.

Not the least help which has been given, help which has only been personally known in full to the Secretary, is financial. But for that help the Society would not be in the position it is to-day.

Council Meeting

A meeting of Council was held in the Offices of the Society on Tuesday, September 11th, 1934.

Present.—Mr. H. E. Wimperis (Vice-President) in the chair. Captain P. D. Acland, Major J. S. Buchanan, Mr. R. S. Capon, Mr. S. Scott-Hall, Mr. F. T. Hill, Major D. H. Kennedy (Honorary Treasurer), Captain A. G. Lamplugh, Mr. M. Langley, Mr. W. O. Manning, Mr. D. R. Pye, Mr. W. P. Savage, Lord Sempill, Lieut.-Colonel F. C. Shelmerdine, Sir John Siddeley, Mr. L. A. Wingfield (Solicitor).

Among the business transacted was the following:—The Wilbur Wright Memorial Lecture; Report of the Finance Committee; Report of the Grading Committee; National Safety First Association; Grant from the Air Ministry; the Engineering Joint Council; Lecture Programme for the Second Half of the 1934-1935 Lecture Session; Students' Flying Club.

Air Ministry Grant

The Air Council have generously renewed their annual grant of £250 a year to the Society, for a further period of five years, beginning in 1935. This year sees the tenth complete year of the grant, which has proved of inestimable value to the Society and enabled the Council to carry out a considerable amount of work which would otherwise have been held in abeyance.

The Council have already written to the Air Council and thanked them for their generosity, but they would like here to give public expression, on behalf of all members of the Society, of the help which has been given during a difficult period.

Elections

At a Council Meeting held on September 11th, 1934, the following were elected:—

Associate Fellows.—Reginald Morville Davy, Frank Charles Lynam, Frederick James Sanger, Arthur Veryan Stephens, Frank L. Wattendorf, Kurt Hermann Weil.

Associate Member.—Jesse Henry Herbert Luxton.

Associates.—Edward Jordan, Rana Denis Shamsher Jung, James Edwin Henty, James Victor Saunders.

Students.—Roy Henry Lewis Arnold, Ernest Henry Cochrane, Donald Fraser, John Hargrave Lerew, John Godfrey Mathieson, Mervyn Lascelles Morris, Dennis Robert O'Brien, Richard Doniville Poland, John Roger St. Claire, Joseph Saoula, James Hay Stevens, Eric Thomas Watkinson, Edward Walpole Whitaker.

National Certificates and/or Diplomas in Mechanical Engineering

The following letters have been exchanged:—

To the Secretary of the Institution of Mechanical Engineers and the Secretary of the Board of Education.

10th May, 1934.

DEAR SIR,

National Certificates and Diplomas in Mechanical Engineering.

The Council of the Royal Aeronautical Society have instructed me to write to you with reference to the endorsement by the President of the Society of National Certificates and/or Diplomas in Mechanical Engineering in respect of Aeronautical Subjects where such are included in approved courses.

The Council would be glad if an arrangement for such an endorsement could be made on the understanding that the Assessor who would be responsible for the criticism of the examination papers and scripts would be appointed after consultation with the Royal Aeronautical Society.

Yours faithfully,

(Signed) J. L. PRITCHARD,

Secretary.

To the Secretary of the Royal Aeronautical Society.

T.500/285 (1). Board of Education, Whitehall, London,

20th June, 1934.

SIR,

I am directed to refer to your letter of the 10th May, 1934, and to state that the Board of Education agree to the proposal for the endorsement of National Certificates and/or Diplomas in Mechanical Engineering by the Royal Aeronautical Society in respect of Aeronautical subjects where such are included in approved schemes.

I am, Sir,

Your obedient Servant,

(Signed) H. B. WALLIS.

To the Secretary of the Royal Aeronautical Society.

The Institution of Mechanical Engineers,
Storey's Gate, St. James's Park, London, S.W.1,

18th June, 1934.

DEAR SIR,

National Certificates and Diplomas in Mechanical Engineering.

I have pleasure in informing you that the Council of this Institution have agreed to the proposal in your letter of the 10th May, 1934, for the Endorsement by the President of your Society of National Certificates and Diplomas in Mechanical Engineering in respect of Aeronautical Subjects where such are included in approved Courses on the understanding that the Assessor for these subjects would be appointed after consultation with the Society.

Steps will be taken in due course to put this arrangement into effect and to make the necessary announcements.

I am, Dear Sir,

Yours very truly,

(Signed) MAGNUS MOWAT,

Secretary.

Advance Proofs

Advance Proofs of the Lectures to be read before the Society may be obtained from 7, Albemarle Street, on payment of 4s. for the first half of the Session, October-December, 1934, or on payment of 8s. for the whole of the Session, October, 1934-April, 1935. Single copies may be obtained at 7d. post free.

International Index

An International Index to Aeronautical Technical Reports has been prepared by the Society of British Aircraft Constructors, Ltd., and is published by the Society at 5s. Net. It consists of 132 pages bound in cloth, and is an index of British, American and foreign technical reports.

The cost of preparing and publishing such an index is heavy, and it can only be published at regular intervals if there is a demand for it. It is hoped that every member will support this index, as it brings their information continually up-to-date from the reports, papers and articles of an aeronautical technical nature throughout the world. The report can be obtained from these Offices, price 5s., or 5s. 4d. post free.

Forthcoming Events

Thursday, October 4th.—Annual General Meeting of the Students' Section, in the Library, at 7.0 p.m.

Saturday, October 6th.—Lecture before Bedales School, by Mr. W. O. Manning, F.R.Ae.S.

Tuesday, October 16th.—Lecture before the Students' Section, by Captain P. D. Acland, in the Library, at 7, Albemarle Street, at 7.0 p.m. Mr. H. E. Wimperis (Vice-President) in the chair.

Thursday, October 18th.—Lecture, "The Education of Aeronautical Engineers," by Professor A. J. Sutton Pippard, F.R.Ae.S., at the Royal Society of Arts, 18, John Street, Adelphi, W.C.2, at 6.30 p.m.

Thursday, October 18th.—"Flying between Kisumu and Cape Town on the Atalanta," Lecture before the Coventry Branch by Captain Caspareuthus.

Thursday, October 18th.—Film of "Wings over Everest," before the Yeovil Branch.

Saturday, October 20th.—Lecture before Aldenham School, by Lieut.-Commander the Hon. J. M. Southwell, A.F.R.Ae.S.

Monday, October 22nd.—Lecture at East Ham Public Library, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

Tuesday, October 23rd.—Meeting of Council in the Library at 5.30 p.m.

Thursday, October 25th.—Lecture, "The Compressed Air Tunnel," by Mr. E. F. Relf, F.R.Ae.S., at the Royal Society of Arts, 18, John Street, Adelphi, W.C.2, at 6.30 p.m.

Thursday, October 25th.—Lecture before the Yeovil Branch, by J. E. Hodgson, Esq., Hon. Librarian, Royal Aeronautical Society, on "Some Pioneers of the Aeroplane."

J. LAURENCE PRITCHARD, *Secretary.*

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

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MONTHLY NOTICES

NOVEMBER, 1934

Council Meeting

A Meeting of Council was held in the Offices of the Society on Tuesday, October 23rd, 1934.

Present: Lieut.-Colonel J. T. C. Moore-Brabazon (President) in the chair; Captain P. D. Acland, Mr. C. R. Fairey (Past-President), Mr. R. S. Capon, Professor F. T. Hill, Mr. J. E. Hodgson (Honorary Librarian), Major D. H. Kennedy (Honorary Treasurer), Mr. W. O. Manning, Major R. H. Mayo, Mr. D. R. Pyé, Mr. W. P. Savage, Mr. S. Scott-Hall, Lieut.-Col. F. C. Shelmerdine, Mr. H. E. Wimperis (Vice-President), Mr. L. A. Wingfield (Solicitor).

Among the business transacted was the following:—National Safety First Council; Students' Flying Club; new premises for the Society; Associate Fellowship and Associate Membership Examinations; Lecture Programme for the second half of the Session; Wilbur Wright Memorial Lecture for 1935; Daniel Guggenheim Medal; Akroyd Stuart Prize.

Elections

Fellows.—William Jolly Duncan, Frederick Tymms.

Member.—Victor Samuel Gaunt.

Associate Fellows.—Geoffrey Uffindell Hayns, Frank Robert Coupland Hounsfield.

Associate Members.—Jack Glover, Joseph Williams.

Associate.—John Fort.

Students.—Reginald Philip Andrews, Ronald Bryce Bridges, Leonard Edward Christmas, Mahendra Narayan Guha, Austin Higgins, Gordon Jefferson, Cyril Woodward Taylor, John Wimperis, Alan Hampden Yates.

Companion.—Nigel Tangye.

Lecture Dinners

As in previous years, the Royal Aero Club are arranging a late dinner for those who attend lectures of the Society. These dinners have been fixed at 2s. 6d. and members of the Society will be made honorary members of the Royal Aero Club for those evenings. It is hoped that as many members of the Society as possible will take advantage of the facilities offered by the Royal Aero Club, whose address is 119, Piccadilly, W.1; telephone Grosvenor 1246-7-8.

Students' Section

The following is a report of the activities of the Students' Section for the Session 1933-1934:—

The officers and members of committee elected at the Annual General Meeting on Wednesday, October 18th, 1933, were:—Chairman—Mr. R. J. Schmidt; Vice-Chairman—Mr. E. C. A. Backhaus; Secretary—Mr. G. L. H. Bott; Committee—J. P. Bertinat, F. G. R. Cook, J. Hanson, R. W. Hase, R. L. Lickley, W. J. S. King-Smith, C. W. Prower, G. H. Mansell.

The Inaugural Address was given by Mr. C. V. Dolby, on Tuesday, 24th October, 1933. The chair was taken by Lieut.-Colonel F. C. Shelmerdine.

The following meetings were held during the Session:—

Tuesday, Nov. 21st, 1933.—" The Use of Compressed Gas in Modern Commercial Aviation," by Mr. L. S. Campbell, Student. In the chair, Mr. F. T. Hill, F.R.Ae.S.

Tuesday, Dec. 5th, 1933.—Debate, " That Airships are not a Commercial Success." Proposed, Mr. C. D. Graham; seconded, Mr. J. W. T. Brackett. Opposed, Mr. J. A. Bailey; seconded, Mr. N. D. New. In the chair, Hon. A. de Moleyns.

Tuesday, Jan. 16th, 1934.—" Aerodromes in England," by Mr. G. H. Mansell. In the chair, Squadron Leader H. N. St. V. Norman, A.F.R.Ae.S.

Tuesday, Jan. 30th, 1934.—" The Covering of Aircraft Wings and Hulls," by Mr. E. C. A. Backhaus, Student. In the chair, Mr. F. A. Foord, A.F.R.Ae.S.

Tuesday, Feb. 13th, 1934.—" Some Notes on Stability of Aeroplanes," by Mr. R. J. Schmidt. In the chair, Dr. H. F. Winny, A.F.R.Ae.S.

Tuesday, Feb. 20th, 1934.—Informal discussion, " The Tendency in the Design of Modern Civil Aircraft," opened by Mr. M. Langley, M.I.Ae.E., and Mr. C. W. Prower.

Tuesday, May 15th, 1934.—" Aircraft Radio (Introductory)," by Mr. Hay Surgeoner. In the chair, Mr. R. P. G. Denman, A.F.R.Ae.S.

The average attendance at these meetings was eighteen.

Visits have been paid to the works of the following firms:—

The De Havilland Aircraft Co., Ltd.

Messrs. Handley Page, Ltd.

The Comper Aircraft Co., Ltd., jointly with Airwork, Ltd., Heston Airport.

Also to:—

The National Physical Laboratory.

The Royal Aircraft Establishment.

During this Session the Committee decided to arrange an informal supper for the Students' Section. This was held on November 28th, 1933, and proved a very successful innovation. Sixty-two members were present.

The Committee has also proposed that a Students' Flying Club be formed. The Council have given the matter their attention, and a special sub-committee has been formed to deal with it.

Acknowledgments

The Council gratefully acknowledge the following: Back numbers of the Journal from Air Commodore H. M. Cave-Browne-Cave, photographs from The

Chance Vought Corporation, lantern slides from Lt.-Commander the Hon. J. M. Southwell, and a collection of N.A.C.A. Reports and Technical Notes from the Air Ministry.

Library

The Library of the Society will, on and after November 10th, 1934, be open on Saturday afternoons between 2 and 5 p.m., instead of 2.30 to 5.30 p.m. as previously.

Forthcoming Events

Thursday, Nov. 1st.—Lecture before the Westland Aircraft Society (Yeovil Branch of the R.Ae.S.), by Mr. G. H. Dowty, A.F.R.Ae.S., M.I.Ae.E., on "Aircraft Undercarriages."

Thursday, Nov. 1st.—Lecture before Royal Grammar School, Newcastle, by Mr. J. Bell, A.R.Ae.S.I.

Saturday, Nov. 3rd.—Lecture before Berkhamstead School, by Lt.-Commander the Hon. J. M. Southwell.

Monday, Nov. 5th.—Lecture before Friern Barnet Literary Society, by Mr. G. O. Waters.

Wednesday, Nov. 7th.—Lecture before Bristol Grammar School, by Captain F. S. Barnwell, F.R.Ae.S.

Thursday, Nov. 8th.—Lecture, "Speeds of Commercial Aircraft," by M. Louis Breguet, in the Lecture Hall of the Royal Society of Arts, 18, John Street, Adelphi, W.C.2, at 6.30 p.m.

Thursday, Nov. 8th.—Lecture before Balshaw's Grammar School, by Mr. G. R. Irvine, A.M.I.Ae.E.

Friday, Nov. 9th.—Lecture before Kingswood Grammar School, by Captain F. S. Barnwell, F.R.Ae.S.

Friday, Nov. 9th.—Lecture before Queen Elizabeth Grammar School, Wakefield, by Mr. G. C. F. Ely.

Friday, Nov. 9th.—Lecture before University College School, by Mr. W. O. Manning, F.R.Ae.S.

Saturday, Nov. 10th.—Lecture before Brighton College, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

Saturday, Nov. 10th.—Lecture before Dean Close School, Cheltenham, by Mr. K. J. Key.

Thursday, Nov. 15th.—Lecture, "Flying Boats," by Mr. I. I. Sikorsky, in the Lecture Hall of the Royal Society of Arts, 18, John Street, Adelphi, W.C.2, at 6.30 p.m.

Thursday, Nov. 15th.—Lecture before the Westland Aircraft Society (Yeovil Branch of the R.Ae.S.), by Mr. W. G. Gibson, A.R.Ae.S., M.I.P.E., on "Aircraft Production Methods."

Thursday, Nov. 15th.—Lecture before the Coventry Branch by Mr. W. C. Devereux, A.F.R.Ae.S., on "The Influence of Manufacture of Wrought and Cast Aluminium Alloys on Design."

Thursday, Nov. 15th.—Lecture before Ryde School, by Mr. T. H. Lloyd, A.F.R.Ae.S.

Friday, Nov. 16th.—Lecture before Wyggeston School, by Mr. C. W. Lewitt, A.M.I.Ae.E.

Saturday, Nov. 17th.—Lecture before Trent College, by Mr. G. R. Irvine, A.M.I.Ae.E.

Saturday, Nov. 17th.—Lecture before Victoria College, Jersey, by Flt.-Lt. C. E. Maslin.

Monday, Nov. 19th.—Lecture before Newcastle-under-Lyme School, by Mr. E. Hill, A.M.I.Ae.E.

Tuesday, Nov. 20th.—Discussion in the Library at 7, Albemarle Street, W.1, on "The Training of Aeronautical Engineers," at 6.30 p.m.

Thursday, Nov. 22nd.—Lecture, "Air Turbulence Near the Ground," by Dr. Wilhelm Schmidt, in the Lecture Hall of the Royal Society of Arts, 18, John Street, Adelphi, W.C.2, at 6.30 p.m.

Thursday, Nov. 22nd.—Lecture before The College, Cheltenham, by Mr. C. C. Copperthwaite.

Friday, Nov. 23rd.—Lecture before Wolverhampton Education Dept., by Captain J. L. Pritchard, Hon. F.R.Ae.S.

Monday, Nov. 26th.—Lecture before Medway Technical College, by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

Tuesday, Nov. 27th.— Lecture before St. Paul's School, by Mr. W. O. Manning, F.R.Ae.S.

Tuesday, Nov. 27th.—Lecture before the Students' Section in the Library at 7, Albemarle Street, W.1, on "Piloting," by Mr. R. W. Hase, Student.

Wednesday, Nov. 28th.—Lecture before St. Germain's School, by Captain F. B. Fanstone, A.F.R.Ae.S.

Thursday, Nov. 29th.—Lecture, "Engine Research," by Captain A. G. Forsyth, in the Lecture Hall of the Royal Society of Arts, 18, John Street, Adelphi, W.C.2, at 6.30 p.m.

Thursday, Nov. 29th.—Lecture before Warwick School, by Mr. P. V. Lamarque, A.F.R.Ae.S.

Thursday, Nov. 29th.—Lecture before the Westland Aircraft Society (Yeovil Branch of the R.Ae.S.), by Mr. B. B. Henderson, on "The Modern Trend of Civil Aircraft Design."

J. LAURENCE PRITCHARD, *Secretary.*

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES

DECEMBER, 1934

Office Closing

The Offices will be closed on Tuesday and Wednesday, December 25th and 26th, for the Christmas holidays.

November Journal

Will those members who received two copies of the November Journal kindly return the extra copy as the stock is very low for this particular month?

Lectures

The attention of all members is particularly drawn to the change in the venue of the lectures and the change of date. Unless otherwise notified, the lectures for the second half of the Session will be held in the Lecture Hall of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2, on *Fridays*.

Dinner to C. W. A. Scott and T. Campbell Black

A Dinner and Dance will be given to Messrs. C. W. A. Scott and T. Campbell Black, winners of the air race from Mildenhall to Melbourne. The dinner and dance, under the auspices of the Royal Aero Club, the Royal Aeronautical Society, the Society of British Aircraft Constructors and the Air League of the British Empire, will be held at Grosvenor House on Wednesday, December 19th, 1934, at 8 p.m.

Members may be accompanied by guests. The price of tickets, exclusive of wines, etc., but including a running buffet until 2.0 a.m., is £1 1s. 0d. each. Members' wishes in regard to seating will be met as far as possible, provided application is made not later than Wednesday, December 12th, 1934. Tables may be booked for any number from four upwards.

Applications for tickets should be addressed to the House Secretary, Royal Aero Club, 119, Piccadilly, London, W.1, and must be accompanied by a remittance in full for the tickets required.

Council Meeting

A Meeting of the Council was held on Tuesday, November 13th, in the Offices of the Society.

Present:—Lieut.-Colonel J. T. C. Moore-Brabazon (President) in the chair; Captain P. D. Acland, Mr. E. C. Gordon England, Major D. H. Kennedy (Honorary Treasurer), Captain A. G. Lamplugh, Mr. M. Langley, Mr. W. O. Manning, Mr. S. Scott-Hall, Lieut.-Colonel F. C. Shelmerdine, Mr. L. A. Wingfield (Solicitor).

Among the business transacted was the following:—Report of the Finance Committee; Report of the Grading Committee; proposed Garden Party at Heston; appointment of an Assessor in Aeronautical Subjects for the National Certificates and Diplomas in Mechanical Engineering.

Elections

The following members were elected at the meeting of Council held on November 13th, 1934:—

Associate Fellows.—Edward Leslie Thomas Barton, Frederick Metcalf Thomas.

Associates.—John Campbell Corlett, Subodh Chandra Moitra.

Students.—Richard Antony Barnwell, William Davidson, Edward Peter Milway, Louis Alexander Howard, Arthur Oliver Mattocks, Kenneth Wilks.

Library

Members are reminded of the hours of opening of the Library, as follows:—

Monday—Friday: 9.30 a.m.—5.0 p.m., except periodical Wednesdays, when it is only open from 9.30 a.m. to 1.0 p.m.

Saturday: 9.30 a.m. to 12.30 p.m.; 2.0 p.m. to 5.0 p.m.

All members of the Society may borrow books or have them sent by post on payment of postage both ways. Books may be retained for three weeks, except in the case of the technical books most in demand, when a week only may be the limit of borrowing. The books reviewed from time to time in the Journal are available for borrowing.

Lecturer-Instructor in Aeronautics

There is a post vacant for a Lecturer-Instructor in Aeronautics at the Johannesburg Day Technical and Trades School Department of the Witwatersrand Technical College. Applicants must hold at least the "A," "B," "C" and "D" licences. Salary scale £400—20—£500. Information regarding conditions of service may be obtained from the London Agents of the College, Messrs. Frank Ross and Company, 9, Fenchurch Avenue, E.C.3, to whom applicants must submit completed forms obtainable from the foregoing, not later than the 22nd December, 1934.

Acknowledgments

The Council desire to gratefully acknowledge the donation of £1 1s. 0d. to the Endowment Fund by Sergeant J. V. Saunders, Associate; copies of back Journals of the Society from Mr. J. Hooley, Mr. C. Matson Hall and Mr. J. Zeidenfeld; and photographs of the Airspeed Courier from Airspeed, Limited.

Lecture Programme

The following Lectures have been arranged for the Second Half of the 1934-1935 Session:—

January 7th.—"Imperial Air Routes," Mr. F. Snowden Gamble.

February 8th.—"Ice Formation in Carburettors," Mr. W. C. Clothier, M.Sc.

February 22nd.—"Research in the R.A.E. Tank," Mr. L. P. Coombes, B.Sc., A.C.G.I.

March 1st.—" Fuels for Aircraft Engines," Mr. E. L. Bass.

March 5th.—" Problems of Cold Presswork," Dr. H. Gough, F.R.S., and Dr. Desch, F.R.S. (Joint Lecture with the Institution of Automobile Engineers and other bodies.)

March 15th.—" New Developments in the Autogiro," Senor Juan de la Cierva, F.R.Ae.S.

March 29th.—" Piloting Commercial Aircraft," Squadron Leader H. G. Brackley, D.S.O., D.S.C., F.R.G.S.

April 12th.—Subject to be announced, Captain G. de Havilland, C.B.E., F.R.Ae.S.

All the lectures will be held in the Lecture Theatre of the Institution of Electrical Engineers, Savoy Place, Victoria Embankment, W.C.2, at 6.30 p.m., except the Joint Lecture on March 5th, which will be held at the Royal Geographical Society, Kensington Gore, S.W.7, at 7.30 p.m.

British Silver Medal for Aeronautics

The British Silver Medal for Aeronautics has been awarded to Messrs. C. W. A. Scott and T. Campbell Black for their achievement leading to the advancement of the science of aeronautics.

Elliott Memorial Prize

The Elliott Memorial Prize has been awarded to Leading Aircraft Apprentice W. Potts, of Halton.

Forthcoming Arrangements

December 3rd.—Lecture before the Institute of the Motor Trade, Manchester, on " The Coming of the Aeroplane," by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

December 4th.—Lecture before the Students' Section in the Library at 7, Albemarle Street, at 7 p.m., on " Air Pilotage," by P./O. R. W. Hase, Student. In the chair, Captain O. P. Jones, R.A.F.O.

December 6th.—Lecture before the Society at the Royal Society of Arts, John Street, Adelphi, at 6.30 p.m., on " Flaps and Other Devices as Aids to Landing," by Mr. R. P. Alston, B.A.

December 10th.—Lecture before Bec School, by Mr. W. O. Manning, F.R.Ae.S., on " How an Aeroplane is Made and Flies."

December 11th.—Lecture before East Ham Public Library, by Mr. G. R. Irvine, A.M.I.Ae.E., on " The Uses of the Aeroplane."

December 12th.—Lecture before Berkhampsted School, by Commander the Hon. J. M. Southwell, A.F.R.Ae.S., on " How an Aeroplane is Made and Flies."

December 13th.—Lecture before the Society at the Royal Society of Arts, John Street, Adelphi, W.C.2, at 6.30 p.m., on " Ferrous Metallurgy in Relation to Aircraft," by Dr. W. H. Hatfield, A.F.R.Ae.S.

December 13th.—Lecture before the Westland Aircraft Society (Yeovil Branch of the R.Ae.S.), by Sir Ernest W. Petter, M.I.Mech.E., on " The Trend of Military Aircraft."

December 14th.—Lecture before Buxton Public Library, on "The Uses of the Aeroplane," by Captain J. Laurence Pritchard, Hon. F.R.Ae.S.

December 19th.—Joint Dinner and Dance with the Royal Aero Club, Society of British Aircraft Constructors, Air League of the British Empire and the Royal Aeronautical Society, to Messrs. C. W. A. Scott and T. Campbell Black, at Grosvenor House. Tickets £1 1s. 0d. each.

December 20th.—Lecture before the Coventry Branch, by Mr. W. S. Farren, M.B.E., M.A., F.R.Ae.S., on "Recent Aeronautical Research at Cambridge University."

December 20th.—Lecture before the Westland Aircraft Society (Yeovil Branch of the R.Ae.S.), by Mr. Leak, on "Cheap Light Aeroplane Design and Construction."

J. LAURENCE PRITCHARD, *Secretary.*